Ponzer & Berns

Effect of Moving Loads
On Highway Bridges

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EFFECT OF MOVING LOADS ON HIGHWAY BRIDGES

BY

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AND

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This is to certify that the thesis of KARL LEWIS PONZER and MAX ARNOLD BERNS entitled Effect of Moving Loads on Highway Bridges is approved by me as meeting this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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EFFECT OF MOVING LOADS ON HIGHWAY BRIDGES.

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I. INTRODUCTION.

The recent desire of engineers to become more familiar with the effect of moving loads on steel bridges is directly the cause of the organization of a corps of engineers to investigate these effects.

The general consensus of opinion is that a load rolled over a bridge does cause many uncertain stresses in the component parts of the structure. Engineers of wide experience have studied this so-called "Impact" stress and have deduced a formulae the use of which tends to insure safety in bridge design. However, the most important step in the study of Impact was the formation of the field corp of the Railway Maintenance of Way Association to examine directly these effects by experiments on railway bridges.

This corps of engineers by care and painstaking have designed a method of proceedure which will be followed in obtaining the data for this thesis.

II. OBJECT OF TESTS.

The lack of sufficient time and an extensive field for experiments has led the writers to select a few important details and to draw, if possible, some general conclusions as to the simultaneous action of component parts of the same member, also the action of like members on spans of about equal length, one having a concrete, the other a plank floor.

III. DESCRIPTION OF INSTRUMENTS.

Deflectometer. Fig. 1. Page 6. The instrument used in the deflection test is fully described in the Transactions of the American Society of Civil Engineers, Vol. XLI, p. 411. It is a simple recording apparatus, which is attached to the structure, and is also connected to the ground underneath by means of a wire attached to a heavy weight which remains on the ground. The wire operates a pencil attached to the instrument on the bridge. The ordinates of the record are double the actual deflection.

Extensometer. Figs. 2 and 3. Pages 6 and 7. This apparatus is an autographic extensometer for recording the deformation of bridge members, and multiplying that deformation by some factor like 80 or 90, and recording it on a moving strip of paper. In Fig. 3, Page 7, the recording end only is shown. This part of the apparatus is clamped to an eye-bar, angle or any projecting corner of a bridge member. Another clamp is attached to the same member at a distance of about 4 feet or more if considered desirable. This latter clamp is connected by a light rod and a universal coupling. The clamps are of such width that they can be easily attached to the outstanding legs of angles, to eye-bars, or to any member not over 3 inches in width. In Fig. 3, Page 7, it will be seen that there are two clamps at the instrument; the one at the left is rigid, while the other is pivoted so as to allow of a slight rocking motion. In the interior of the apparatus is a rod running from the long connecting rod to the short end of a lever on which it has a knife-edge bearing. The long end of the lever carries the pencil, which records its movements upon a travelling strip of

glazed paper driven by clock-work. This lever is made of aluminum so as to be as light as possible and at the same time very stiff. F. E. Turneaure is the designer of this instrument.

Fig.1 Deflectometer in place on Hip Vertical of
Market St Bridge

Fig.2 Extensometer in place on Hip Vertical of
Market St. Bridge

Fig. 3. Recording End of Extensometer.

IV. DESCRIPTION OF BRIDGES TESTED.

The bridges tested were:

(1). Market Street Bridge.

(2). Blackberry Bridge.

(3). Schwartz Bridge.

(4). St. Joe Bridge.

(5). Mahomet Bridge. (160 foot span).

(6). Mahomet Bridge. (144 foot span).

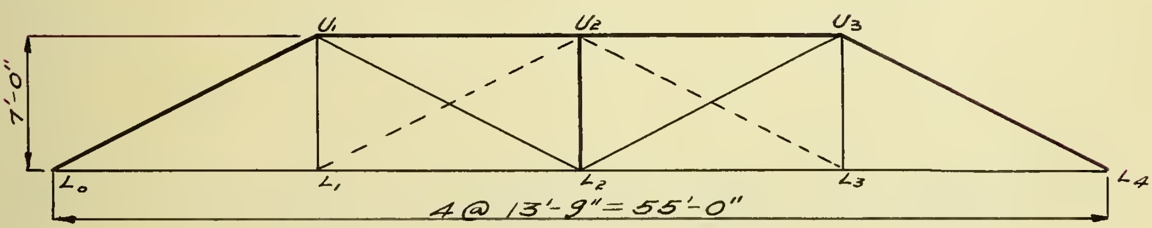


Fig. 4. Bridge No. 1.

Bridge No. 1. This is known as the Market Street Bridge and is located north of the city district of Urbana, on Market Street across the Salt Fork Drainage Ditch. It is a highway bridge with a cantilever sidewalk supported on the east truss. All tests were made on the west truss, it being impossible to attach the instruments to the lower chord of the truss where the cantilever sidewalk was hung.

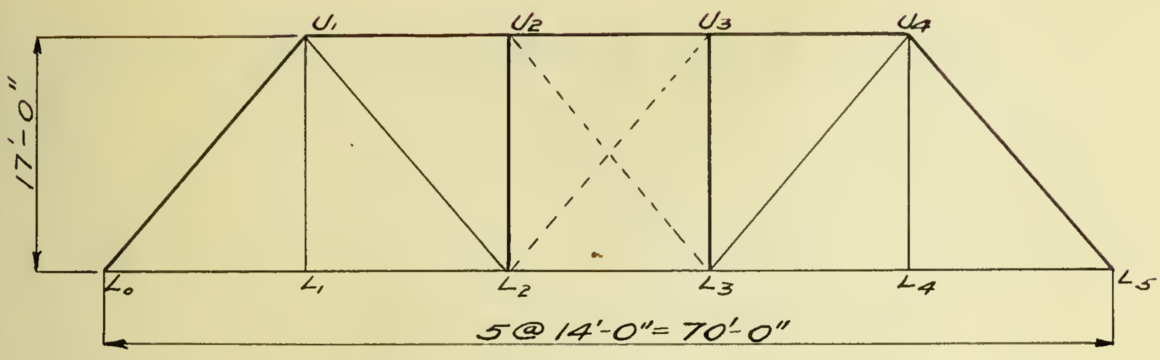


Fig. 5. Bridge No. 2.

Bridge No. 2. The Blackberry Bridge is located east of Urbana, 3 miles farther down the same ditch crossed by the Market Street Bridge. It has a plank floor with a 14' 0" roadway.

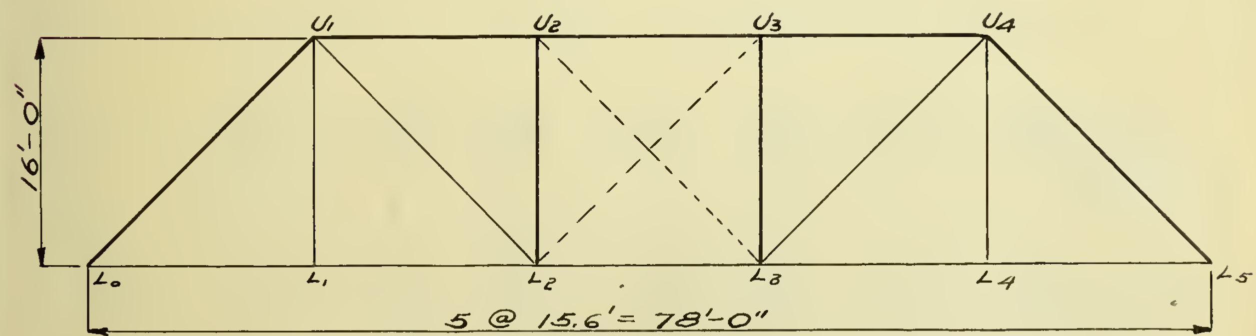


Fig. 6. Bridge No. 3.

Bridge No. 3. The Schwartz Bridge spans the Salt Fork Drainage Ditch about midway between the Market Street and the Blackberry Bridges. This bridge has a 14.0 foot concrete floor and is similar in general design to Bridge No. 2 with which it is compared as regards relative effects of floor weights. (See Art. 6).

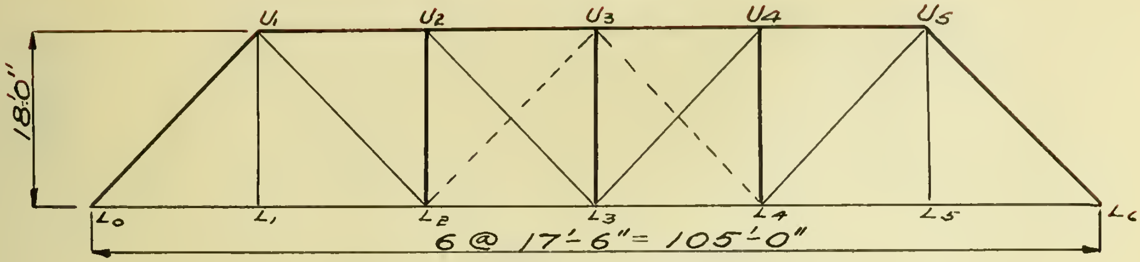


Fig. 7. Bridge No. 4.

Bridge No. 4. The St. Joe Bridge is located just west of St. Joe, Illinois, across the Salt Fork branch of the Illinois River. The flooring is of plank and is 16 feet wide.

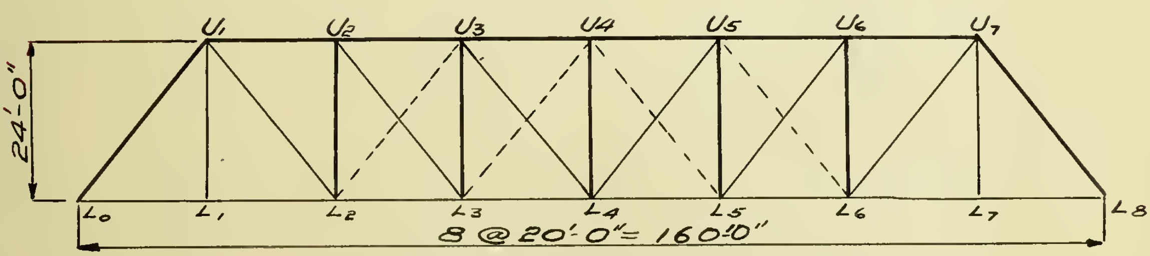


Fig. 8. Bridge No. 5.

Bridge No. 5. The Mahomet Bridge (160 foot span) crosses the Sangamon River about 1 1/2 miles southwest of Mahomet, Illinois. The distance between trusses is 17.0 feet, and it has a plank floor.

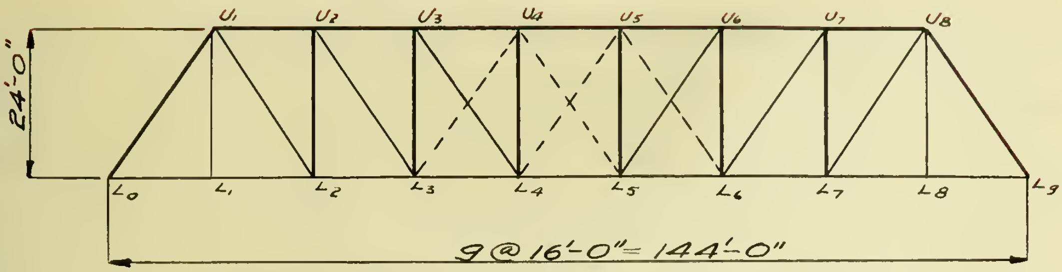


Fig. 9. Bridge No. 6.

Bridge No. 6. The second Mahomet Bridge (144 foot span) is about 3 miles north-east of Mahomet, Illinois. It also crosses the Sangamon River. Bridge No. 6 has a 14.0 foot reinforced concrete floor.

V. METHOD OF MAKING TESTS.

The four extensometers and the deflectometer were attached to different members of a bridge and run simultaneously by electrical connections with magnets attached to clock-work of each instrument. The extensometers were usually attached in pairs, e.g. E_7 on the inside bar or flange and E_8 on the corresponding outside bar or flange of the same member; or, E_7 on the outside bar of a member on, say, the north truss and E_8 on the outside bar of the corresponding member of the south truss. (See Fig. 12 Page 14). The deflectometer was usually attached to a post of the central panel. In this way the relative stresses in similar parts of bridge members were obtained for like loads, speeds and directions. This method gives an opportunity of comparing the component parts of same members under exactly parallel conditions.

No attempt has been made to compare the computed and actual values, as lack of time for calculations, and lack of sufficient field data would not enable the writers to make comparisons from which reliable conclusions could be drawn.

Instead of drawing up the diagrams for each instrument separately and consecutively as is usually done, an attempt has been made to collect significant diagrams on the same page. That is, on any one page will be found the diagrams for component parts for a particular bridge member, with like speeds and loads grouped in sequence and under one another. By this method the effects of speed as well as the different actions of component parts of a member can be directly compared from the diagrams.

On pages 91 to 95 are compared a concrete floor bridge with a plank floor bridge. These two structures were of almost

identical design and span; and therefore a fairly good comparison of the effect of the different floors is readily made. Here, too, the diagrams for like members under nearly identical conditions are grouped together.

Three different classes of loads were ordinarily used. Horse, double rig and driver- the ordinary "buggy load ; same as above closely followed by a horse, single rig and driver- the so-called double header (d. h.) noted under the diagrams; and on some bridges an automobile of the large touring car type. With the horses three distinct types of speeds were used, namely, a walk (2 to 4 miles per hour), a trot (5 to 10 miles per hour, and a gallop (12 to 18 miles per hour). On some of the best diagrams the effects of the beats of horses hoofs can be distinctly seen. For the automobiles, speeds varying from 5 to 40 miles per hour were obtained. Because of poor approaches to the bridges 40 miles per hour was the maximum obtainable, and this is very likely a higher speed than any at which a machine would ordinarily cross the bridges.

The speed for horse drawn rigs was obtained by noting the time with a stop watch which it took to travel over a 100 foot base line laid off on the bridges. From curves carried in the field, this speed was immediately converted to miles per hour. The automobiles had speedometers attached and the speed was taken directly from these. (See Fig. 15, Page 16).

Fig. 10. Buggy Load Crossing St. Joe Bridge.

Fig. 10-a. Buggy Load Crossing Mahomet Bridge.

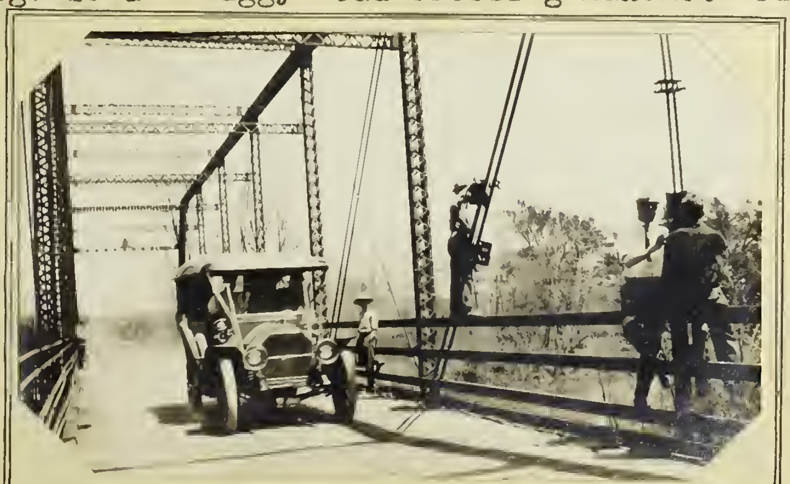


Fig. 11. Automobile Load Crossing Mahomet Bridge.

Fig.12 Extensometers in place on Diagonals of St. Joe Bridge.

Fig. 13. Automobile used on Mahomet Bridges. Field Party.

Fig. 14. Bridge No. 5, Mahomet, Illinois.

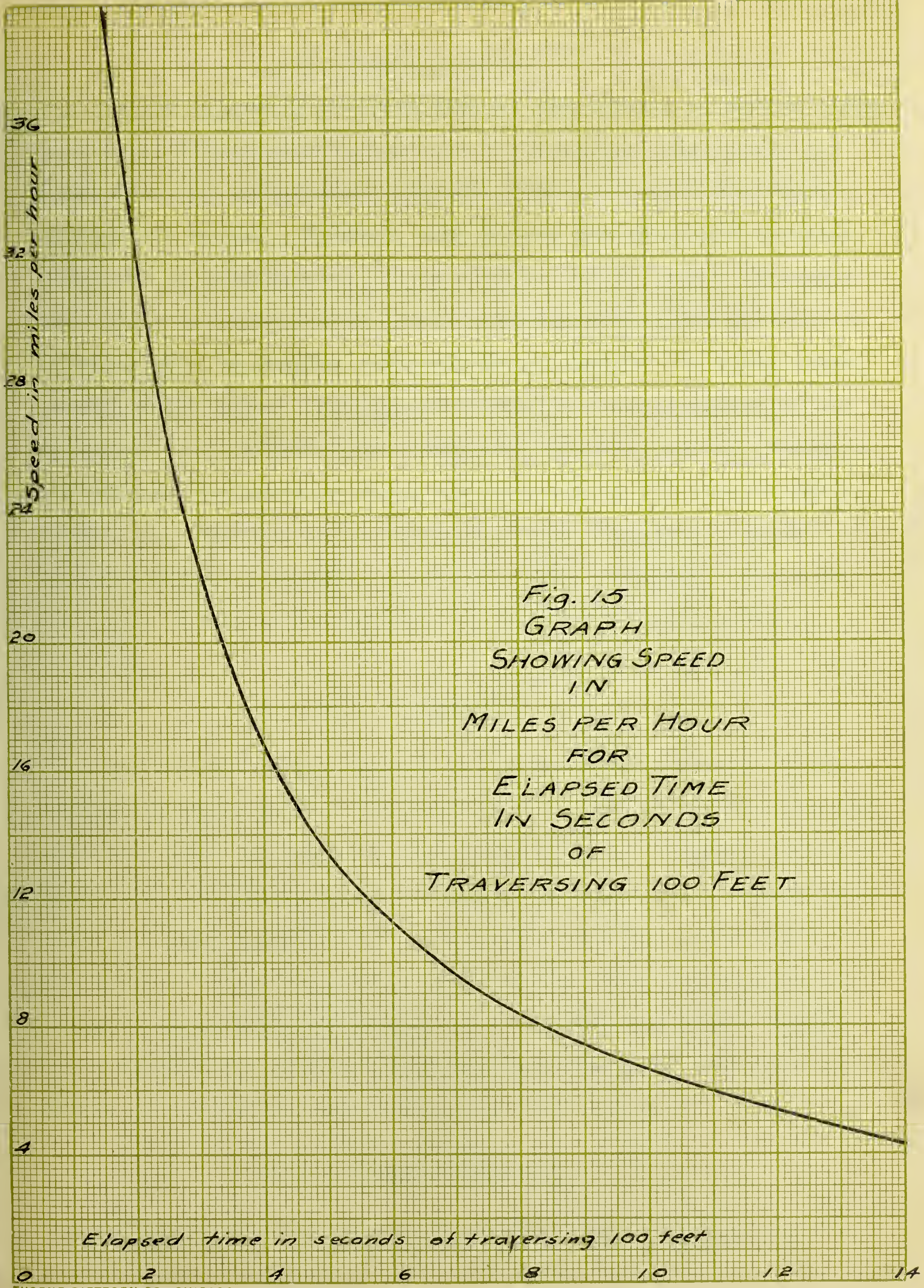


Fig. 15
GRAPH
SHOWING SPEED
IN
MILES PER HOUR
FOR
ELAPSED TIME
IN SECONDS
OF
TRAVERSING 100 FEET

VI. PHASES STUDIED.

In the following articles some of the effects of Moving Loads on Highway Bridges are brought out. These are principally deduced from the autographic diagrams, copies of which are found on pages 29 to 95. However, some of the features were strongly impressed by observations in the field. It is beyond the scope of this paper to explain these field observed deductions inasmuch as it would require lengthy explanations as regards the load, speed, direction of travel, position of instruments and diagrams of the bridges. It is a well known fact that some engineering phenomena are obtained in practice which are contrary to all theoretical deductions. Suffice it to say that in the discussions which follow nothing is brought out which is not indelibly stamped on the minds of the experimentors from actual practical tests.

Art. 1. Impact.

The writers do not take up the study of this stress in the bridges as fully as the co-workers in this set of experiments and therefore give reference to the thesis of H. B. Anderson and W. E. Lord, 1910, in which impact is studied by its effect on members of short and long spans, by its effect on center and end members, by its increase or decrease with speed of the load, and also by its variation in members of bridges with concrete and plank floors. These results are obtained from the same series of tests and are worthy of perusal in connection with this thesis.

Art. 2. Tension Members.

On page 25 are recorded some tension members of all the

bridges with the percent of total stress and impact in percent of the stress carried by each part of the member.

From these results it is seen that the two parts of tension members do not always act simultaneously; for example, the action of member U_1L_2 Bridge No. 4 recorded on pages 47 and 45 shows that the outside bar carries seventy percent of the stress and the inside bar thirty percent. (See Table 1, page 25).

Some members show a variation of stress as much as eighty percent, and this is not infrequent. The causes of this are apparently the difference in length of the members and the imperfections of erection. The former is evidently the chief cause for it can be seen by the tension in the member due to dead load, one member being loose and easily shaken while the other is taught and not easily shaken. The second cause is likely to occur in spans erected by inexperienced workmen such as are, in many cases, employed on highway bridges. This neglect of care in erection can easily throw the bridge a little out of line and so cause the same effect as a long or short member.

The impact in these parts varies considerably, ranging from twenty to three hundred percent of the stress carried by each component. The lower percents of impact are found in the structures with concrete floors and will be further discussed in Art. 6. In the members of the bridges having plank floors it is found that the impact varies from ninety to three hundred percent and this tends to prove that at least one hundred percent impact should be used in design of all tension members.

A study of the built-up tension members immediately shows the different percents of impact. On page 67 is shown a comparison

of the tension bars of a hip vertical under the same loadings as the built-up section of the same member. In the tension bars the percents of impact are enormous in comparison with impact in the rigid section of the same member.

The same action is shown on built-up sections of Bridge 1. This is discussed in the next article.

Art. 3. Compression Members.

In the study of the actions of the different parts of compression members reference is made to the thesis of R. C. Collins, '09, who made tests similar to those in this thesis. From the curves recorded by instruments in his experiments on top chord members and end posts, it is seen that the same variation of percent of stress carried, occurs in the different parts. However, little or no impact is recorded, the curves in general being almost straight lines.

Investigation of the built-up tension member U_1L_1 of the Market Street Bridge shows like variations in percents of stress carried by the outside and inside flanges, but as in chord members, shows very little impact stresses.

These results seem to indicate a solution for the problem of minimizing impact stresses, namely, to make all members of built-up sections.

In so far as these results to a degree show a method for decreasing impact stresses they do not, however, show that stresses carried by different parts of compression members are in correct proportion to the respective areas.

Art. 4. Tension Members of Different Trusses.

Comparisons made with similar members of different trusses in the same structure show but small variation as regards total stress carried by each member. That is, when the stresses carried by each component part are added, the total obtained is the same as a like total for the same member of the opposite truss. The variation is so slight when it is remembered that an allowance must be made for errors in reading instrumental records as well as allowing for a difference in the instruments themselves, that it may be said that the ordinary practice of designing like members of opposite trusses to take equal stresses is amply safe and in accordance with results obtained from actual tests.

Art. 5. Compression Members of Different Trusses.

Little can be said regarding the action of compression members of different trusses. The recording of exact action of these members is extremely difficult and also so small that it is somewhat uncertain to draw conclusions as to the actions.

The intermediate parts act in the same manner as most all built-up members; and little impact is shown. This again shows the advisability of using built-up sections to resist impact stresses. The same general conclusion as brought out in Art. 4 will apply to compression members also.

Art. 6. Effect of Floor Weight.

This particular phase of the tests could be accurate in so far as deductions are more evident, and marked differences occur in

the action of spans having concrete and plank floors. On pages 91 to 95 are compared by means of instrumental records, the impact and actual stresses in the members.

The bridges having plank floors obtain the maximum stresses when the load passes over the floor beam connected at the panel point to which the lower end of the member is connected, while in the bridges with concrete floors the structure acts as a beam and the load at any point stresses the members at some distance from the point considered.

The concrete floor tends to make the structure act as a unit. Evidence of this fact is strikingly illustrated by the records on Bridge No. 6, pages 35 and 36 where the structure was felt to vibrate as a whole immediately after the load came on the bridge. The records show this same fact by the steady increase and decrease of the deflection and stress curves.

The stresses in bridges with concrete floors are well distributed over the entire structure, making the actual live load stress less in any particular member than it would be for a plank floor bridge where the effect of the moving load is more or less localized. In addition to this advantage as regards live loads, the percent of impact is seen to be almost negligible for bridges with concrete floors.

Art. 7. Effect of Speed.

In trusses covered with plank floors the impact vibrations increased with an increase of speed up to maximum obtained in some bridges, while others had a speed of lower than the maximum to

give greatest impact stresses. This is probably caused by the uneven panel lengths in the various structures, and also shows that the structure does not act wholly as a rigid beam. In the structures where concrete floors are used the speed only affects the bridge in so far as there is a critical speed for each structure, at which speed the structure and the hoof beats of the horse are in the same phase and with each step of the horse, the vibration increases.

This, too, shows that the floor has a great influence on the stability of the bridge in so far as it helps or deters the structure from acting as a unit.

Other speeds than this critical speed fail to show any vibrations worthy of note, and only the intermittent steps of a horse give such vibrations as can be easily recorded or noticed.

Moving loads which do not have distinctive shocks as they pass over the bridge give very little impact stress. This was indicated in the investigations of concrete floored bridges where the hoof beats of the horse could be traced over the bridge by use of the record obtained. Automobiles running at high and low speeds gave scarcely any impact stresses, while the live load stress increased with the speed.

Art. 8. Effect of Classes of Traffic.

The loads used on the bridges were automobiles,and horses attached to light rigs.

The spans having plank floors were subjected to heavy impact stresses when automobiles were used, the stresses being caused by the uneven floor and loose boards. The horse and buggy also

produced proportionately large impact stress. In all spans having plank floors an automobile travelling at speed from 20 to 40 miles per hour gave the greatest localized stresses and impact. In spans having floors of concrete there was no speed for the automobile which gave any impact or localized stress worthy of note, but in the same spans there were impact stresses recorded when the critical speed was obtained with horse and buggy. From the results obtained and recorded in the succeeding pages of this thesis it is evident that in all country bridges the allowance for impact is entirely too small, even when allowance of 100 percent is made.

The loads that are used in making designs are considerable in excess in weight of those used by the experimentors in their thesis, and so designs made using the standard loading for highway bridges in a way takes care of the large impact stresses due to the lighter moving loads. It is evident that they are safe for a number of years but probably are cut short in life by the imperfect design for impact stresses.

Art. 9. Effect of Classes of Bridges.

Experiments made in this thesis were on light highway bridges designed for a moving load of 16,000 pounds distributed on two axles, six feet apart.

One span was a short Pony truss while others varied in length from 56 to 160 feet. These spans as a rule increased in heighth as length increased. Scarcely any differences can be noted in the stresses and impact of long and short tension members, but considerable difference is noted in the stresses and impact of the Pony and the Pratt trusses. The floor system in the

former evidently is the chief cause of the difference and it is almost wholly a difference of impact stresses.

Built-up members of the higher trusses show a small percent of increase in impact and instrumental vibration. This fact only tends to prove still more conclusively that the length divided by least radius of gyration is an important feature in bridge design.

More difference seems to be attributed to long and short panels rather than high or low trusses. This part was noticed on spans having panels varying from 12 to 20 feet, the impact and actual stresses increasing with the panel length.

Table I

Table Showing Variation of Stress and Impact

Diagram on page	Bridge No.	Member Tested	Percent of Total Stress		Percent of Impact		Speed in miles per hour	Load
			Inside bar	Outside bar	Inside bar	Outside bar		
66	4	Hip Vertical, U_1L_1	50	50	140	100	12.0	Rig
64	3	" " U_1L_1	10	90	50	90	23.0	Auto.
65	3	" " U_1L_1	10	90	50	90	12.5	2 Rigs
41	1	Diagonal U_3L_2	90	10	100	50	14.8	1 Rig
38	1	" U_1L_2	60	40	120	100	27.0	Auto.
54	2	Diagonal U_2L_3	25	75	250	200	26.0	"
54	2	Counter U_3L_2	50	50	300	225	26.0	"
45	3	Diagonal U_1L_2	70	30	120	100	12.5	2 Rigs
44	3	" U_1L_2	70	30	100	100	18.0	1 Rig
47	4	" U_1L_2	45	55	90	90	12.0	"
48	4	" U_2L_3	45	55	110	130	20.5	"
49	5	" U_1L_2	20	80	150	200	15.0	"
73	2	Lower Chord L_1L_2	10	90	200	40	23.0	Auto
74	3	" " L_1L_2	30	70	70	50	11.5	2 Rigs
75	3	" " L_2L_3	50	50	70	20	17.0	"
76	4	" " L_1L_2	40	60	40	45	16.6	1 Rig
77	4	" " L_2L_3	90	10	100	90	16.6	"
78	4	" " L_3L_4	40	60	150	200	18.0	"

VII. CONCLUSIONS.

It is evident from records shown that the empirical formulae and also approximate allowances for impact vibrations are in many cases utterly inadequate, and had the structures tested been designed for the moving load used in tests, failures would have occurred or at least, the materials would have been stressed many times the unit stress used in design.

It is seen that more metal in a bridge makes the structure less susceptible to vibratory shocks and impact stresses. This is well worth consideration when figuring the life of the structure.

The discussion in Art. 6, on concrete and wooden floors tends to confirm the deduction that increase of metal or weight lessens impact as well as actual live load stresses.

The results of the tests show that a moving load scarcely affects members distant from the point where the load comes on the bridge; also, that a concentrated moving load causes remarkable impact stresses in members of panels having counters, and especially so in the counters themselves.

From discussions of built-up sections it is concluded that the economical design would be to place metal as far from the center of gravity of section as possible and thus minimize the stresses due to moving loads.

Hardly a test was made which in itself would furnish complete evidence of the behavior of any member or truss under the particular conditions of loading.

A brief discussion of the vibration of Bridge No. 6 under a trotting horse is sufficient to show that rigidly connected trusses which have floors of considerable weight and rigidity do

act as a vibrating string and have a critical speed that is more destructive than greater loads under different speed.

With each test made greater interest arose in results obtained and at completion of the three hundredth test numerous effects of moving loads on highway bridges still remained uninvestigated.

From the foregoing discussion the following conclusions have been drawn; namely:

1. For similar kinds of loads the stress increases directly as some power of the load.

2. The stress increases directly as some power of the speed, except as noted below.

3. Generally a trotting horse produces less stress and impact than a galloping horse. When, however, the sequence of hoof beats are in the same phase as the vibrations of the bridge, large deflections and hence large stresses are caused. The speed causing this is called the critical speed, and may occur when the horse is trotting as on Bridge No. 6.

4. Component parts of the same member do not act together, the outer flange of built-up sections and the outside bars of tension members taking the greatest stress.

5. The stresses in the component parts of a member vary as the stresses in the member.

6. Built-up tensions members have much less impact than bars, and distribute the live load more equally.

7. Except in the case of sympathetic vibrations, the direction of approach of the load has no affect on stress or impact.

8. Practically, like members of different trusses in the same span share the loads equally.

9. Members which theoretically should take equal stresses, as L_0L_1 and L_1L_2 seldom do so.

10. Faulty work in the shops and in erection cause unequal stresses in members or components of some member theoretically supposed to be equal.

11. Bridges with concrete floors distribute the live load over a greater portion of the structure, thus really lessening the actual live load in any particular member.

12. Bridges with concrete floors have very little impact, partly due to distribution of live load.

VIII. AUTOGRAPHIC DIAGRAMS.

A. DEFLECTOMETER.

B. EXTENSOMETER.

1. Tension Members.

   a. Main diagonals.

   b. Counters.

   c. Hip verticals.

   d. Lower chords.

2. Compression Members.

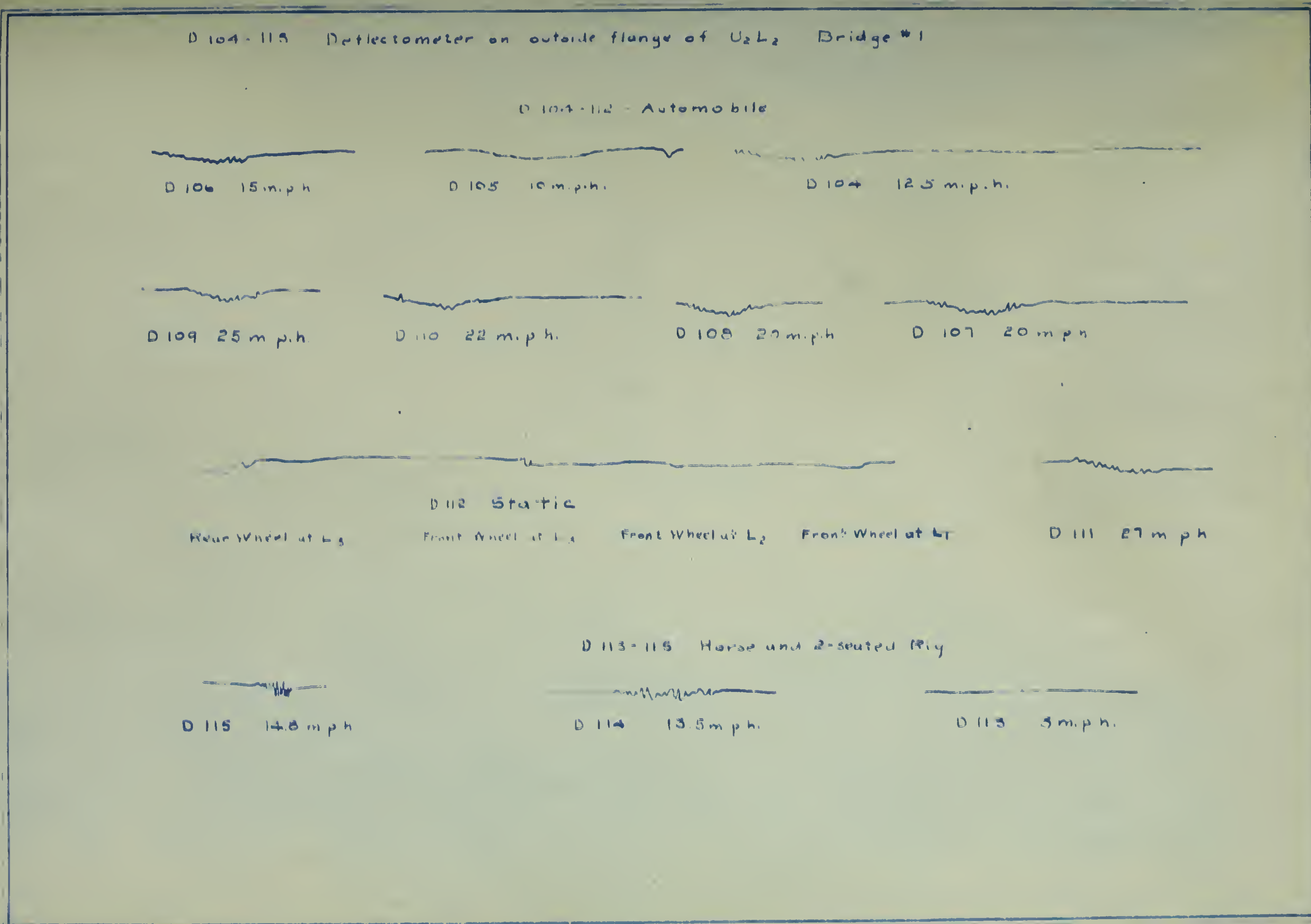
   a. End posts.

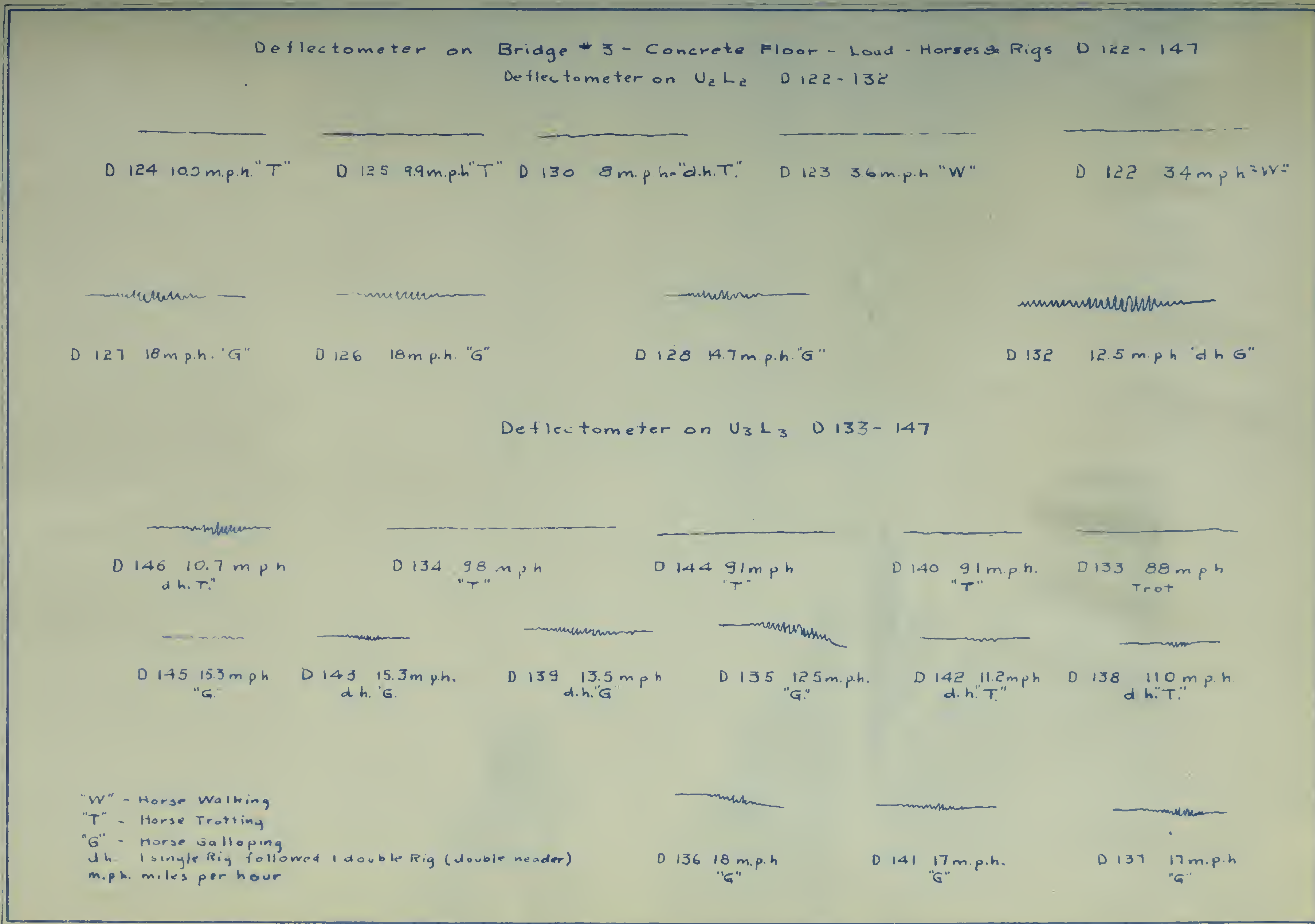
   b. Intermediate posts.

   c. Upper chords.

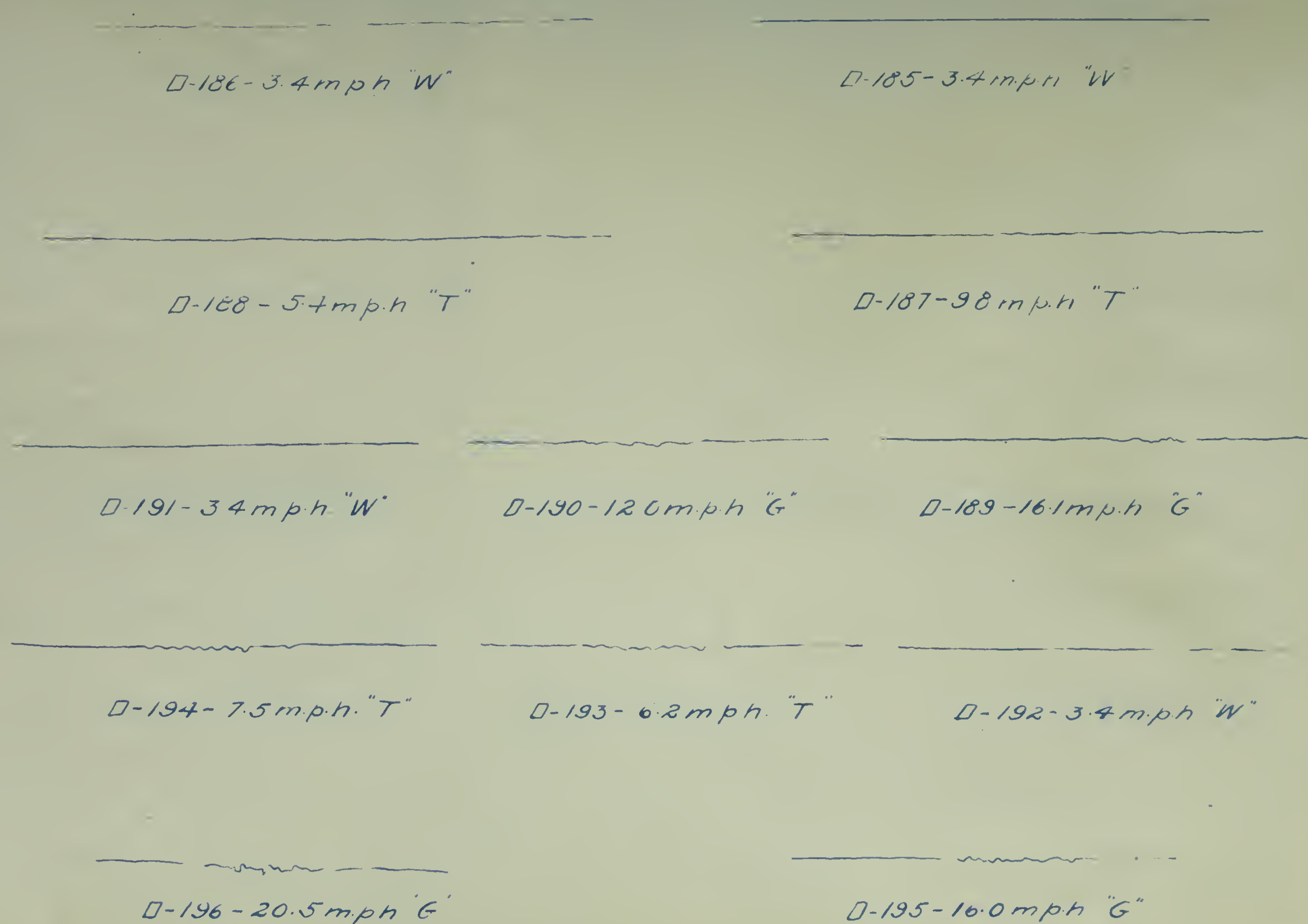
C. COMPARISON OF FLOOR WEIGHT.

A. D E F L E C T O M E T E R


D 104 - 115 Deflectometer on outside flange of U2 L2 Bridge #1
D 104 - 112 - Automobile
D 106 15 m.p.h
D 105 10 m.p.h.
D 104 12.5 m.p.h.
D 109 25 m.p.h.
D 110 22 m.p.h.
D 108 20 m.p.h
D 107 20 m.p.h
D 112 Static
Rear Wheel at L3
Front Wheel at L2
Front Wheel at L1
D 111 27 m.p.h
D 113 - 115 Horse and 2-seated Rig
D 115 14.8 m.p.h
D 114 13.5 m.p.h.
D 113 5 m.p.h.

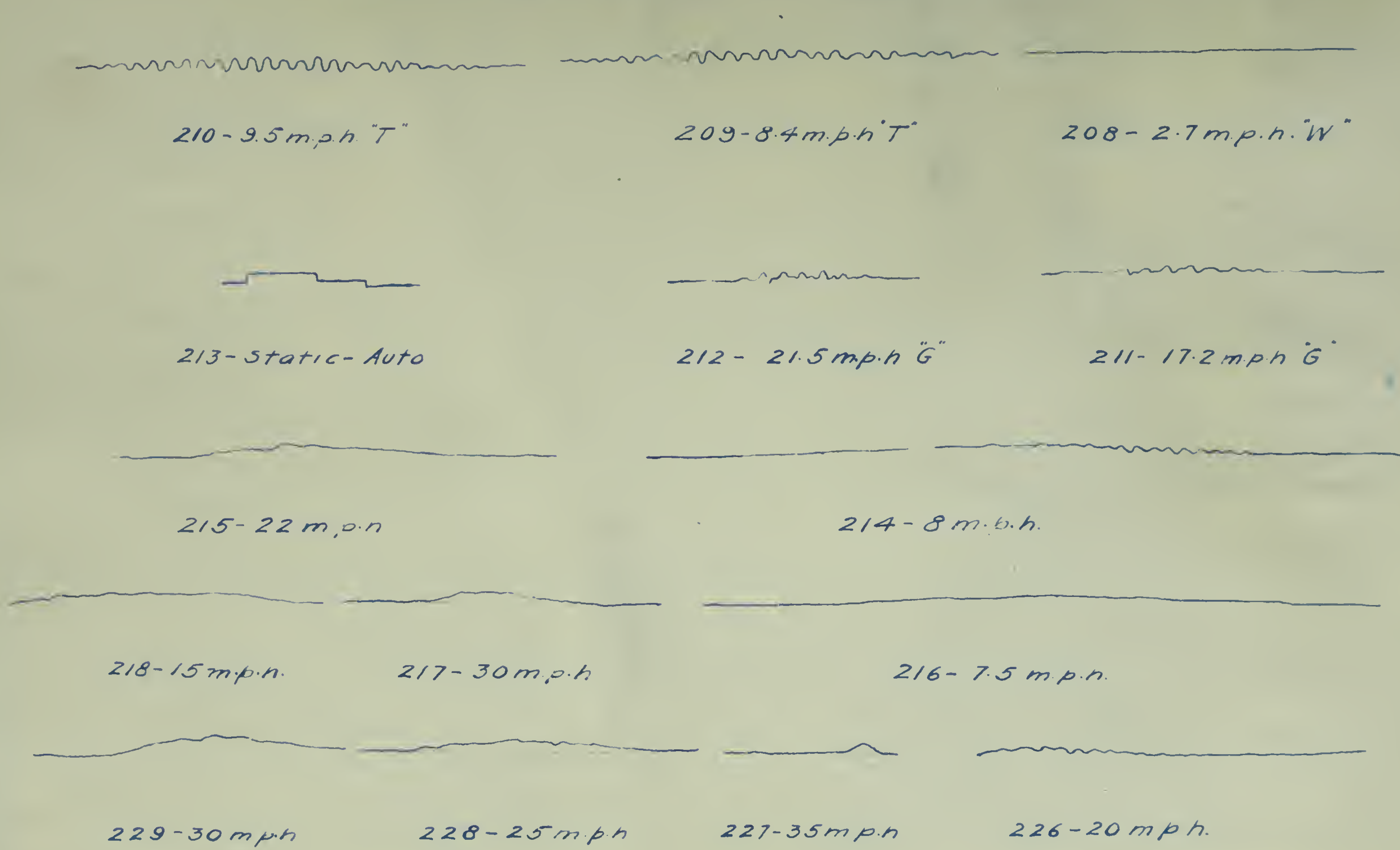

Deflectometer on Bridge # 3 - Concrete Floor - Loud - Horses & Rigs D 122 - 147
Deflectometer on $U_2 L_2$ D 122 - 132
D 124 10.0 m.p.h. "T"
D 125 9.9 m.p.h "T"
D 130 8 m.p.h. "d.h.T."
D 123 3.6 m.p.h "W"
D 122 3.4 m p h "W"
D 127 18 m p.h. "G"
D 126 18 m p.h. "G"
D 128 14.7 m.p.h. "G"
D 132 12.5 m.p.h "d h G"
Deflectometer on $U_3 L_3$ D 133 - 147
D 146 10.7 m p h d h. T.
D 134 9.8 m p h "T"
D 144 9.1 m p h "T"
D 140 9.1 m.p.h. "T"
D 133 8.8 m p h Trot
D 145 15.3 m p.h. "G."
D 143 15.3 m p.h. d h. G.
D 139 13.5 m p h d.h. G
D 135 12.5 m.p.h. "G."
D 142 11.2 mph d. h. "T."
D 138 11.0 m p. h. d h. "T."
"W" - Horse Walking
"T" - Horse Trotting
"G" - Horse Galloping
d h. 1 single Rig followed 1 double Rig (double header)
m.p.h. miles per hour
D 136 18 m.p.h "G"
D 141 17 m.p.h. "G"
D 137 17 m.p.h "G"

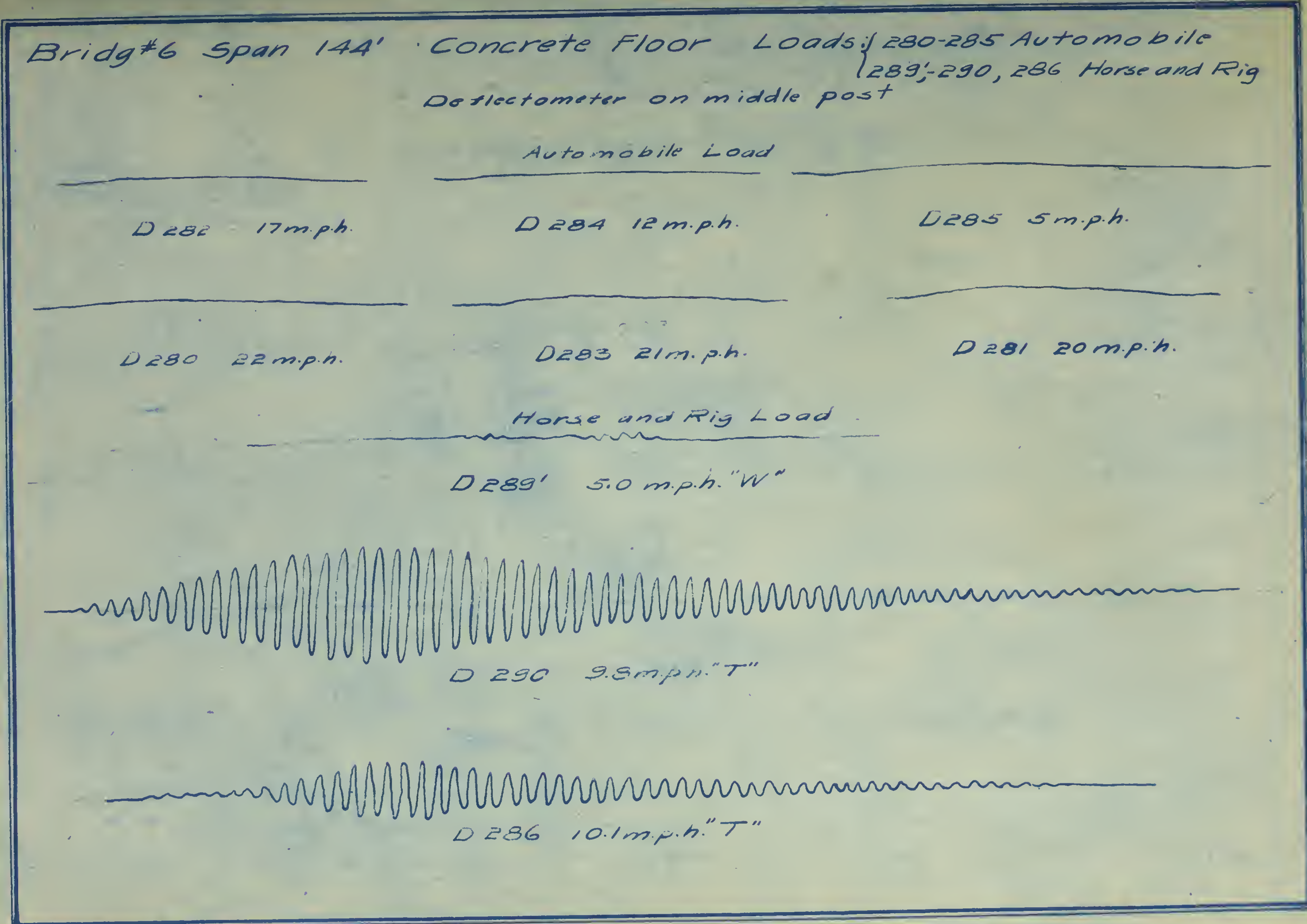
Bridge #4 Span 105' Deflectometer on outside flange of U_3L_3 Load - Horse and Buggy



Bridge #5 Deflectometer on U_4L_4

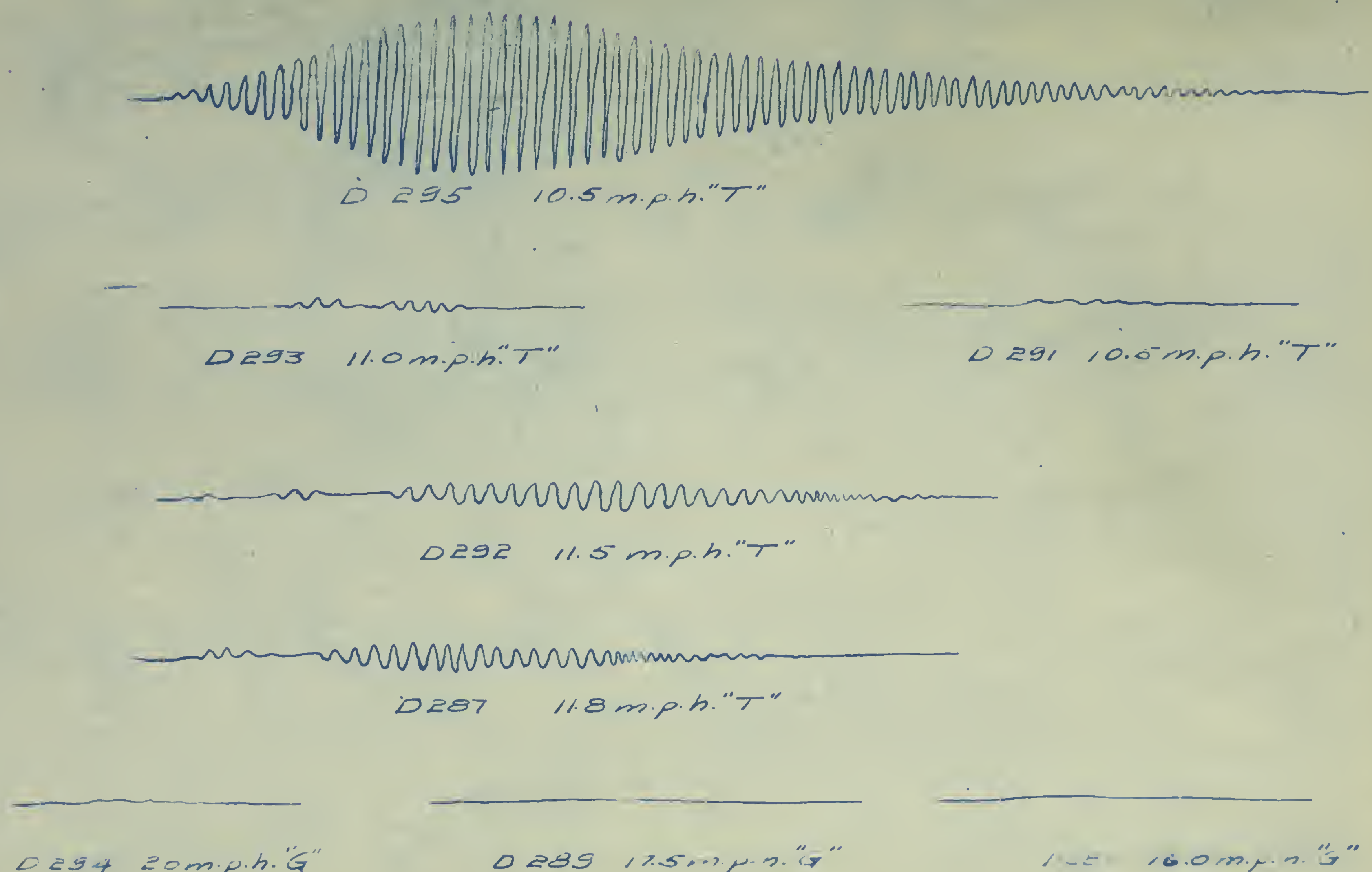
Load 208-212 Horse and buggy 213-218 and 226-229 Automobile




Bridg #6 Span 144' Concrete Floor Loads: 280-285 Automobile
289'-290, 286 Horse and Rig
Deflectometer on middle post
Automobile Load
D 282 17 m.p.h.
D 284 12 m.p.h.
D285 5 m.p.h.
D280 22 m.p.h.
D283 21 m.p.h.
D 281 20 m.p.h.
Horse and Rig Load
D 289' 5.0 m.p.h. "W"
D 290 9.8 m.p.h. "T"
D 286 10.1 m.p.h. "T"

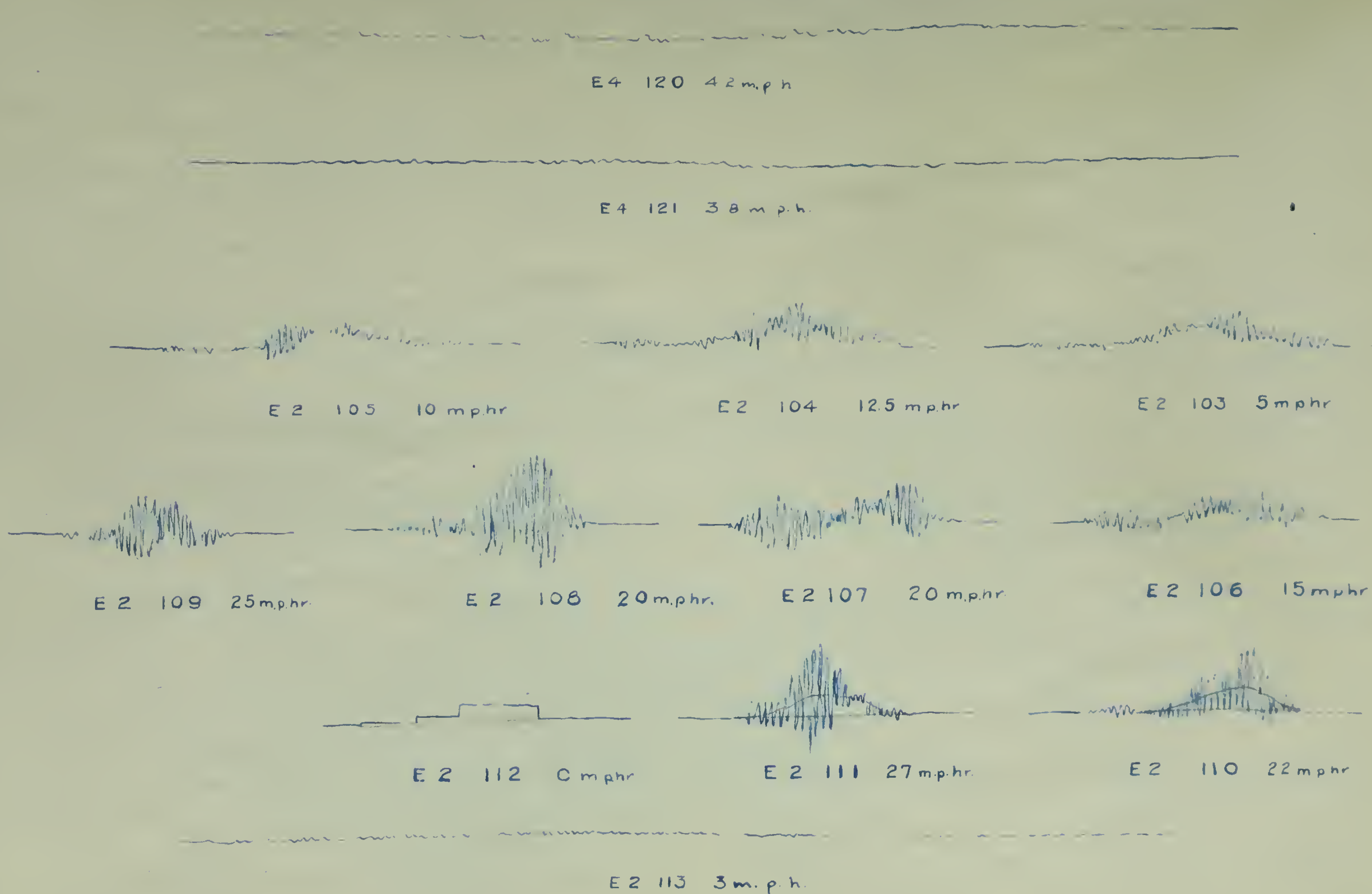
8100
.009
72.900

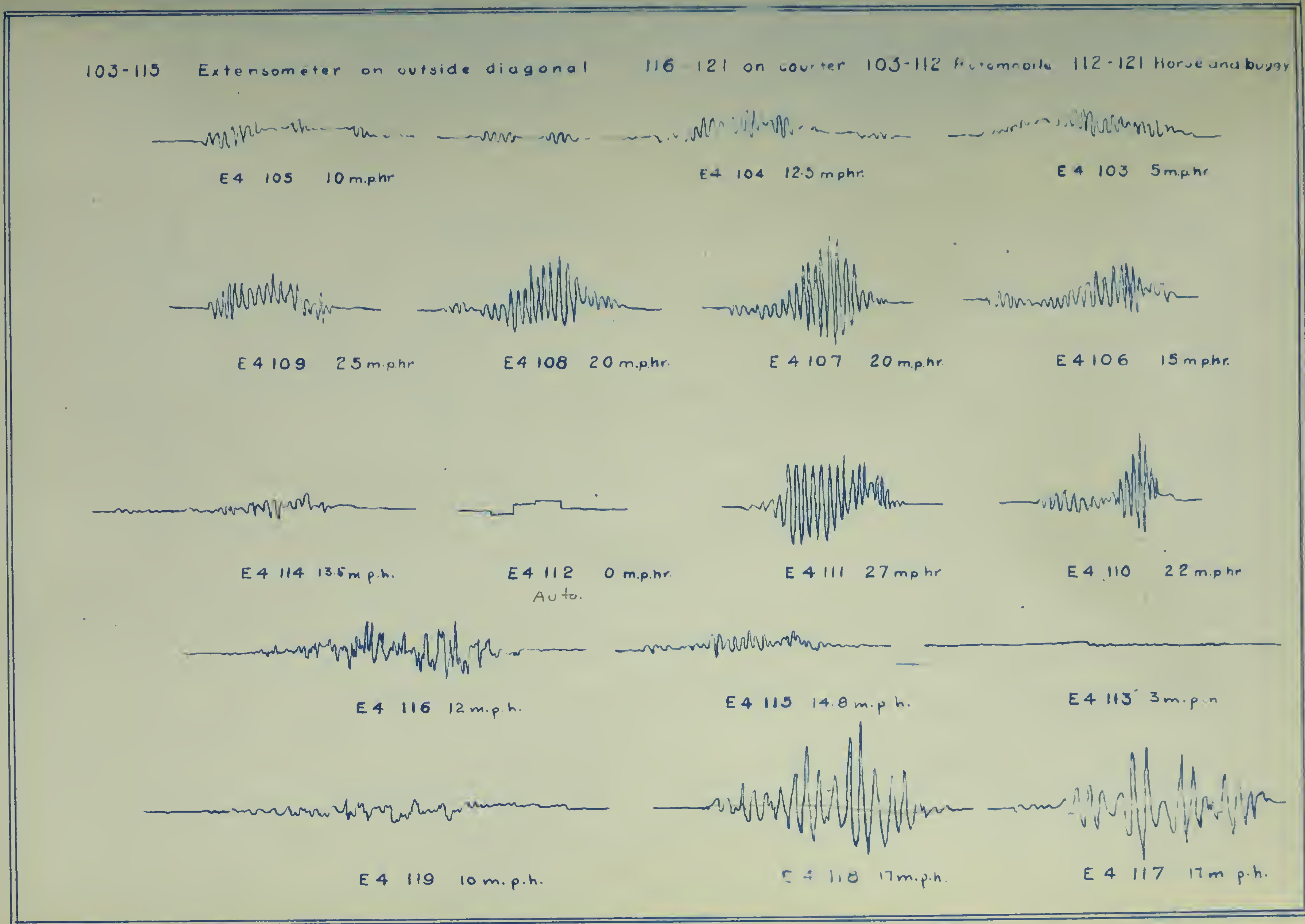
Bridge #6 Span '144' Concrete Floor Load: Horse and Rig
Deflectometer in Center

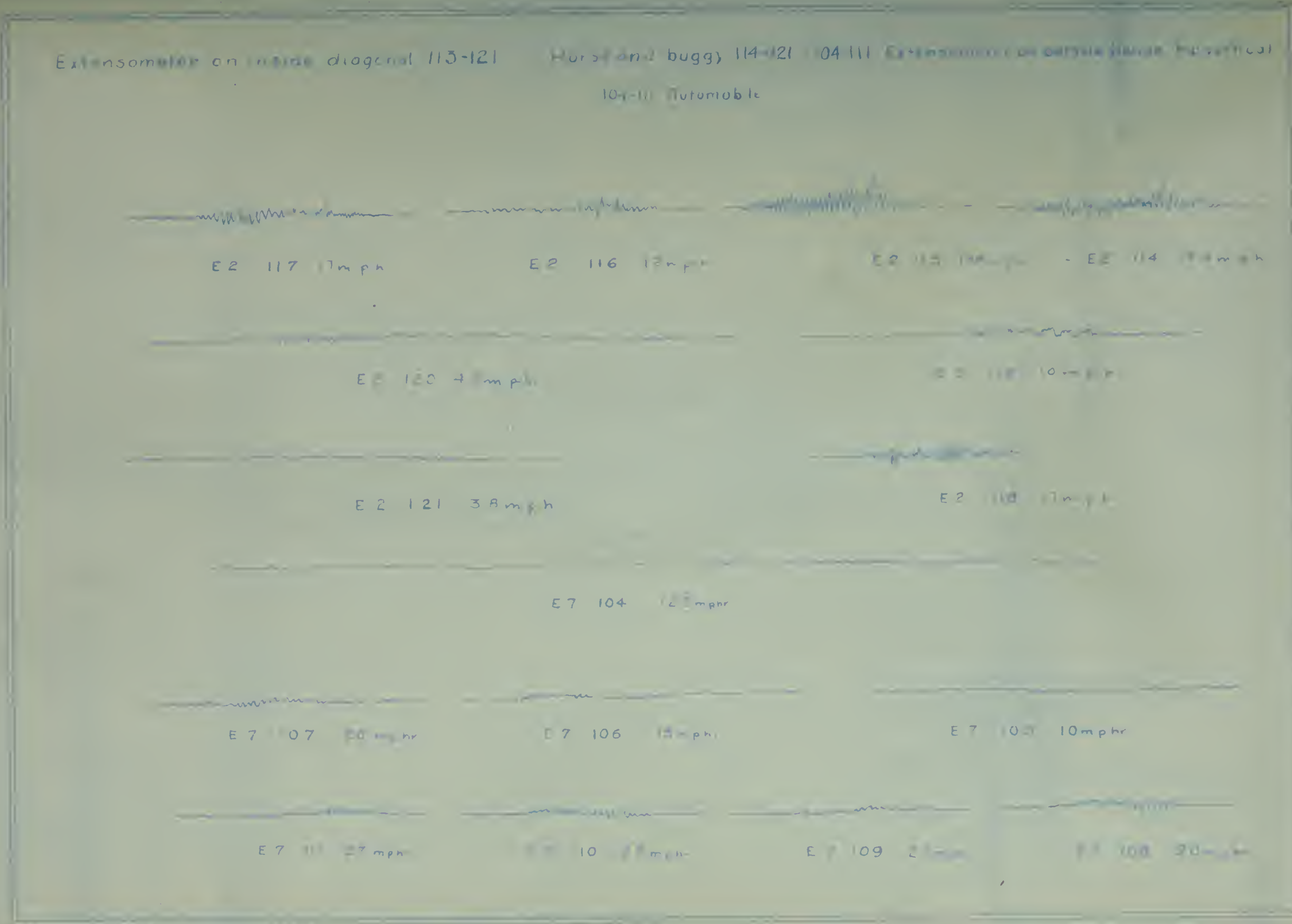


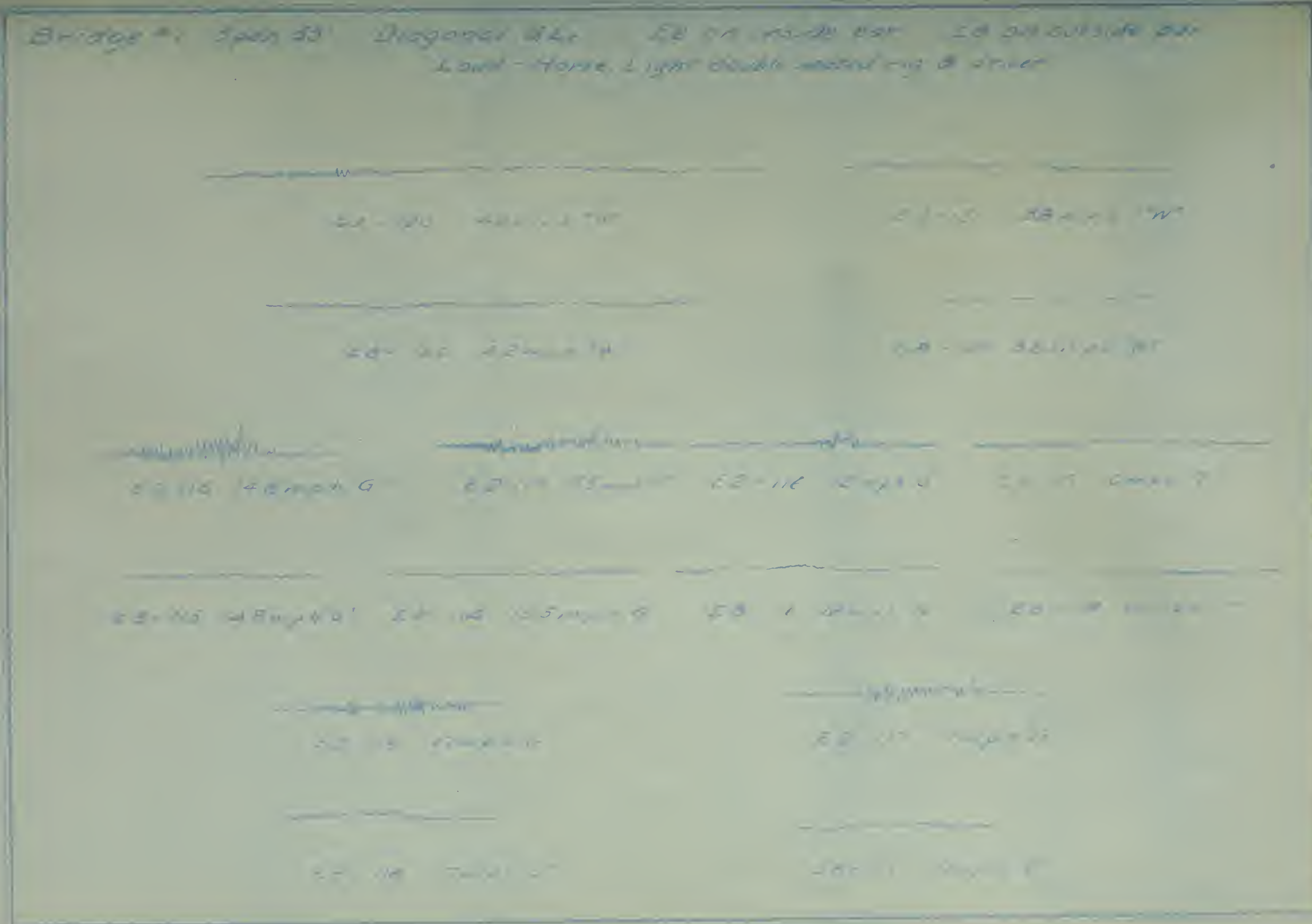
a. M A I N D I A G O N A L S .

103-115 Extensometer on inside diagonal Automobile 103-112



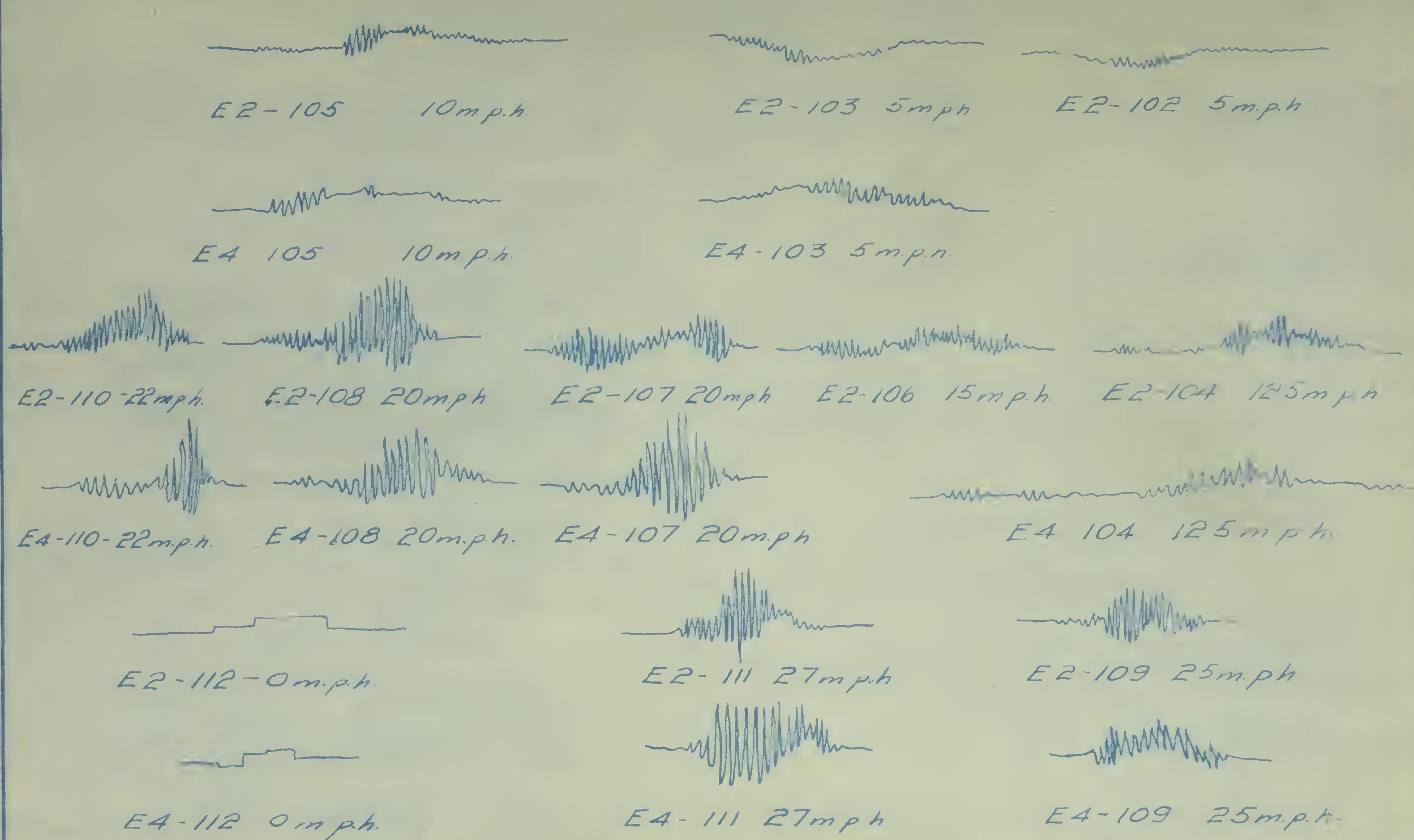

103-115 Extensometer on outside diagonal 116-121 on courter 103-112 Automobile 112-121 Horse and buggy
E4 105 10 m.p.hr
E4 104 12.5 m phr.
E4 103 5 m.p.hr
E4 109 25 m.p.hr
E4 108 20 m.p.hr.
E4 107 20 m.p.hr.
E4 106 15 m.p.hr.
E4 114 13.5 m p.h.
E4 112 0 m.p.hr.
Auto.
E4 111 27 mp hr
E4 110 22 m.p hr
E4 116 12 m.p.h.
E4 115 14.8 m.p.h.
E4 113 3 m.p.h
E4 119 10 m.p.h.
E4 118 17 m.p.h.
E4 117 17 m p.h.


Extensometer on inside diagonal 113-121
bugg 114-121 104 111
104-111 Automobile
E2 117
E2 116
E2 121 38mph
E7 104
E7 106
E7 10mphr
E7 10
E7 109

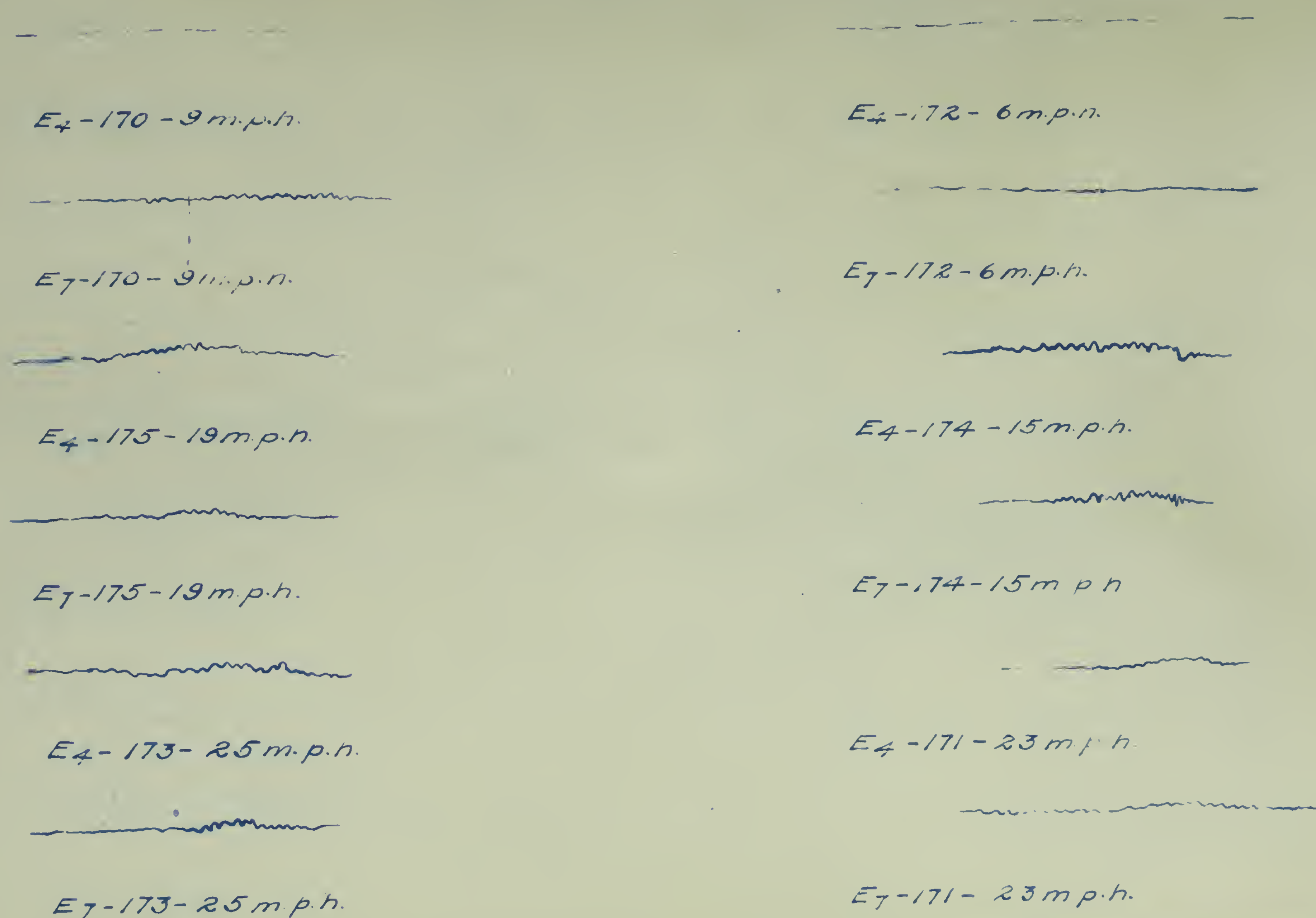


Bridge #1 Diagonal U_2L_3 E2 on inside bar, E4 on outside bar

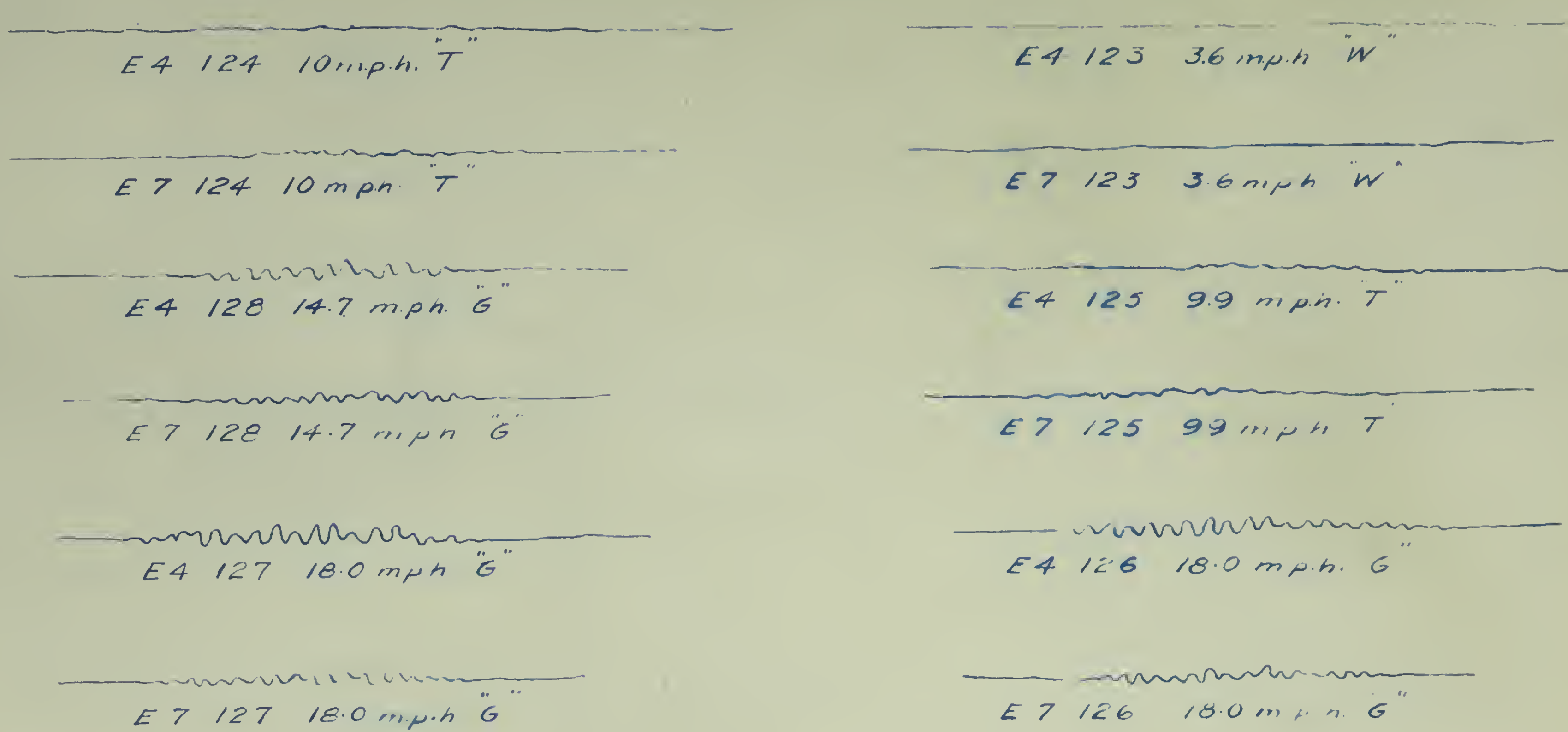
Automobile load



Bridge #3 Diagonal U_1L_2 E_4 on inside E_7 on outside
Load – Automobile



Bridge $^{\#}3$ Diagonal U_1L_2 E 4 on inside E 7 on outside Load Horse and 2 seated rig



Bridge #3 Diagonal U_1L_2 E4 on inside E7 on outside Load-Horse and single rig followed by horse and 2 seated rig

E4 130 8.0 m.p.h. "T"

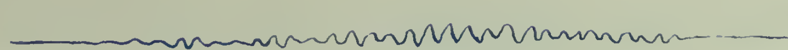
E4 129 3.1 m.p.h. "W"

E7 130 8.0 m.p.h. "T"

E7 129 3.1 m.p.h. "W"

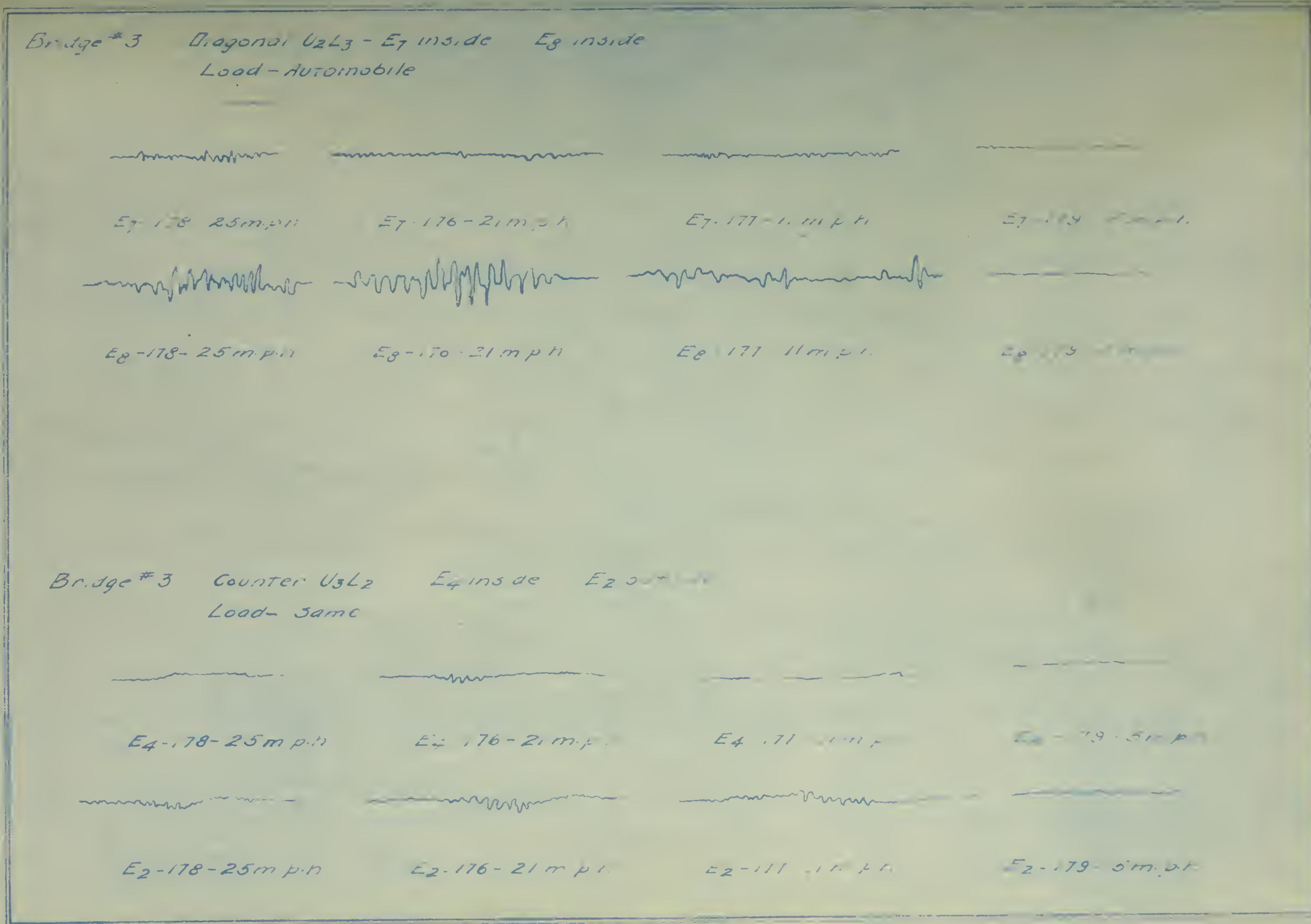
E4 132 12.5 m.p.h. "G"

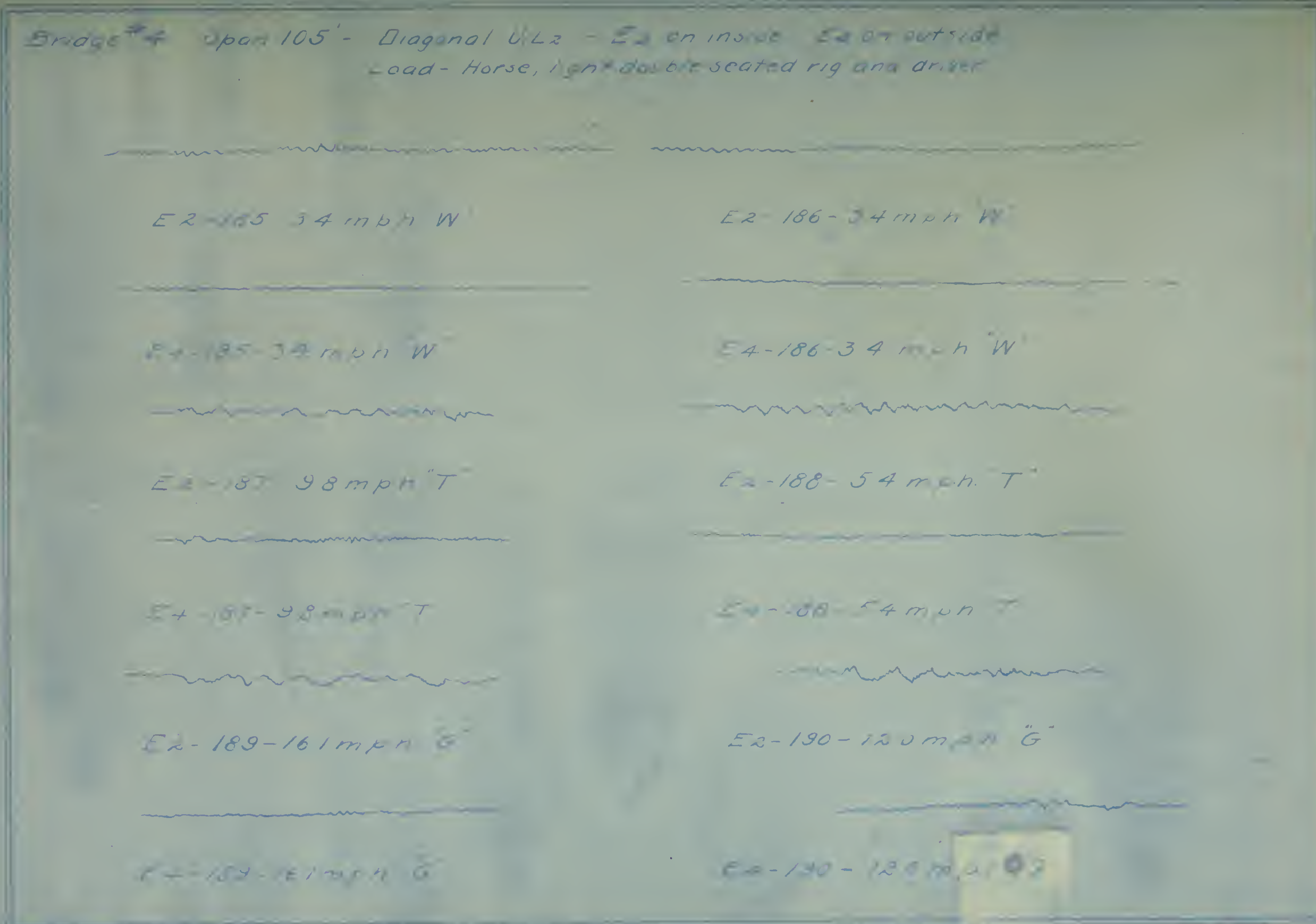
E4 131 14.0 m.p.h. "G"



E7 132 12.5 m.p.h. "G"

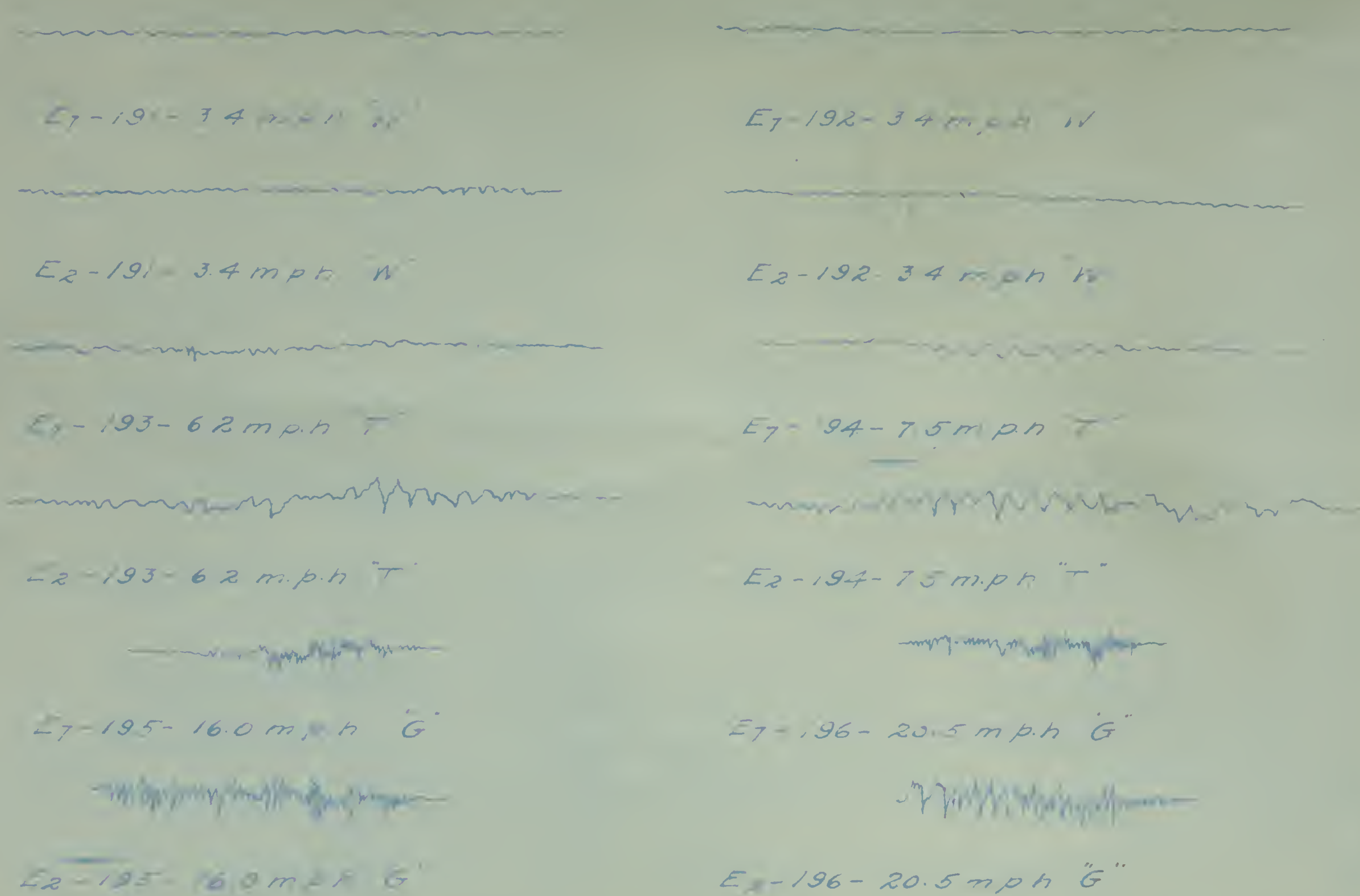
E7 131 14.0 m.p.h. "G"


Bridge #3 Diagonal U_2L_3 - E_7 inside E_8 inside
Load - Automobile
E_7 - 176 - 21 m.p.h
E_8 - 178 - 25 m.p.h
E_8 171 11 m.p.h
Bridge #3 Counter U_3L_2 E_4 inside E_2
Load - Same
E_4 - 178 - 25 m.p.h
E_4 176 - 21
E_2 - 178 - 25 m.p.h
E_2 - 176 - 21 m.p.h
E_2 - 179 - 5 m.p.h

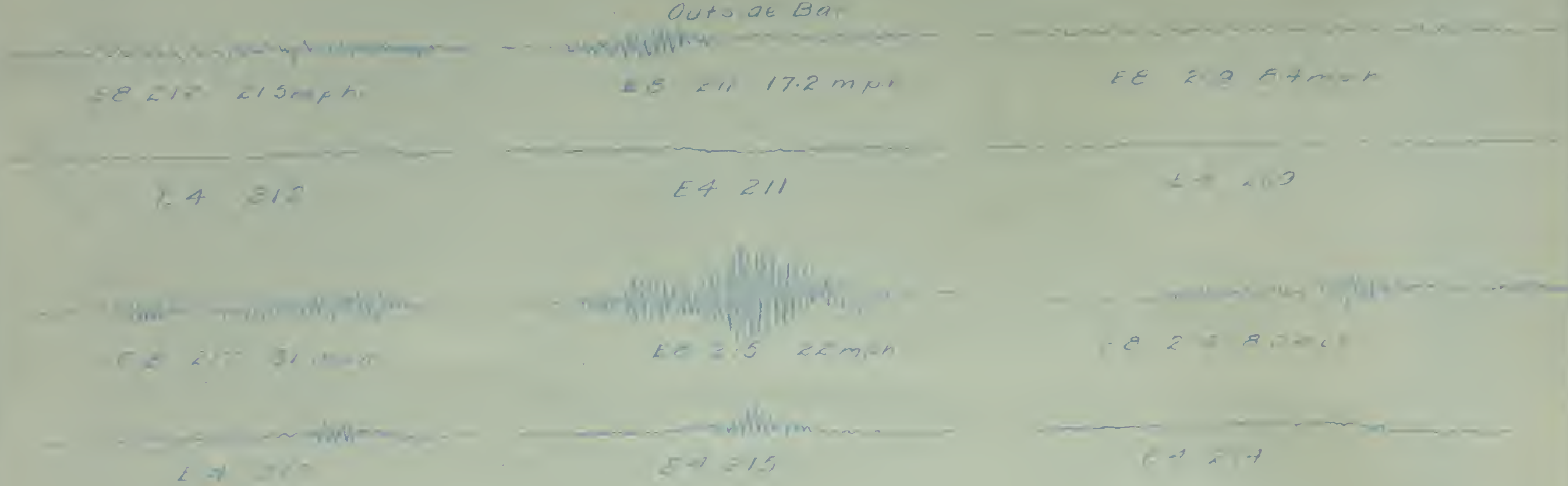

Bridge #4 Span 105' - Diagonal U₁L₂ - E₂ on inside E₄ on outside
Load - Horse, light double seated rig and driver
E2-185 34 mph W
E2-186-34 mph W
E4-185-34 mph W
E4-186-34 mph W
E2-187 98 mph "T"
E2-188-54 mph. "T"
E4-187-98 mph "T"
E4-188-54 mph "T"
E2-189-161 mph "G"
E2-190-120 mph "G"
E4-189-161 mph "G"
E4-190-120 mph "G"

Bridge [illegible] Diagonal U_2L_3 E_1 on inside E_2 on outside

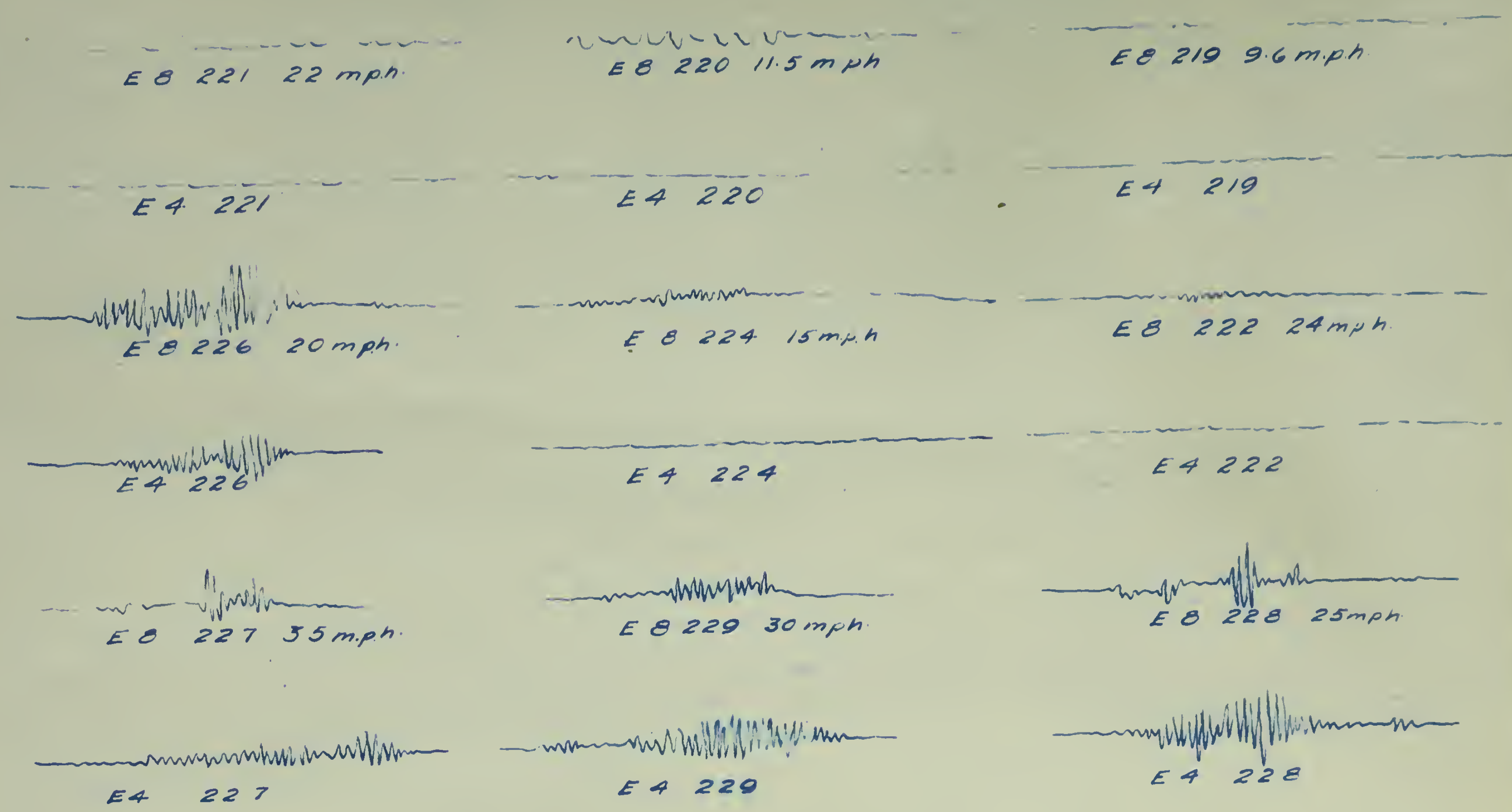
Load - horse and light double seated rig



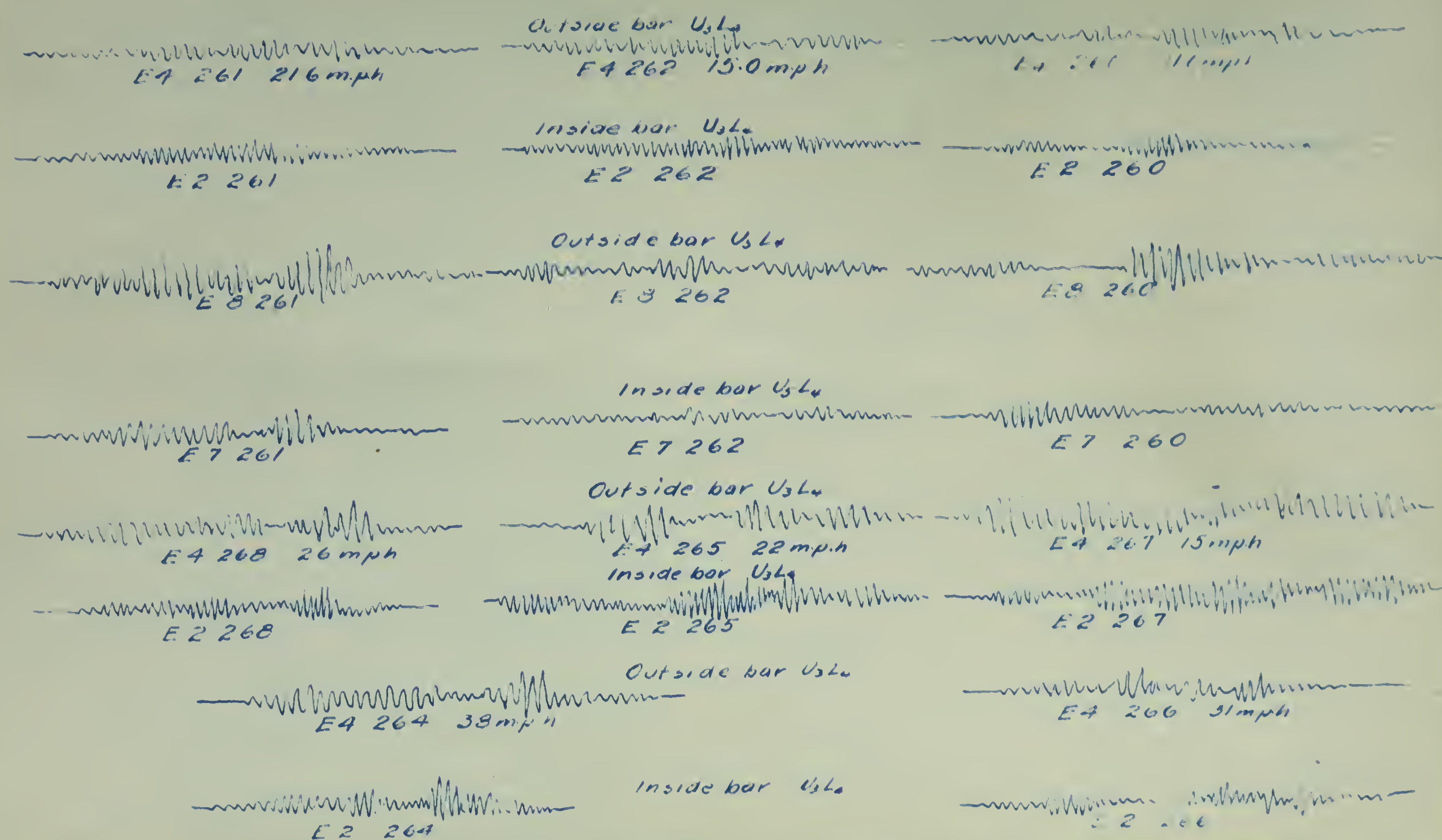
Diagonal U.L. B.5 209 212 Accelerating 214 217 Automobile



Diagonal U_1L_2 Br 5 East truss 219 222 Horse & rig 224-229 Automobile E8 outside bar E4 inside



Diagonals U_3L_4 and U_5L_4 260-262 Horse & rig 264 268 Automobile B1 5

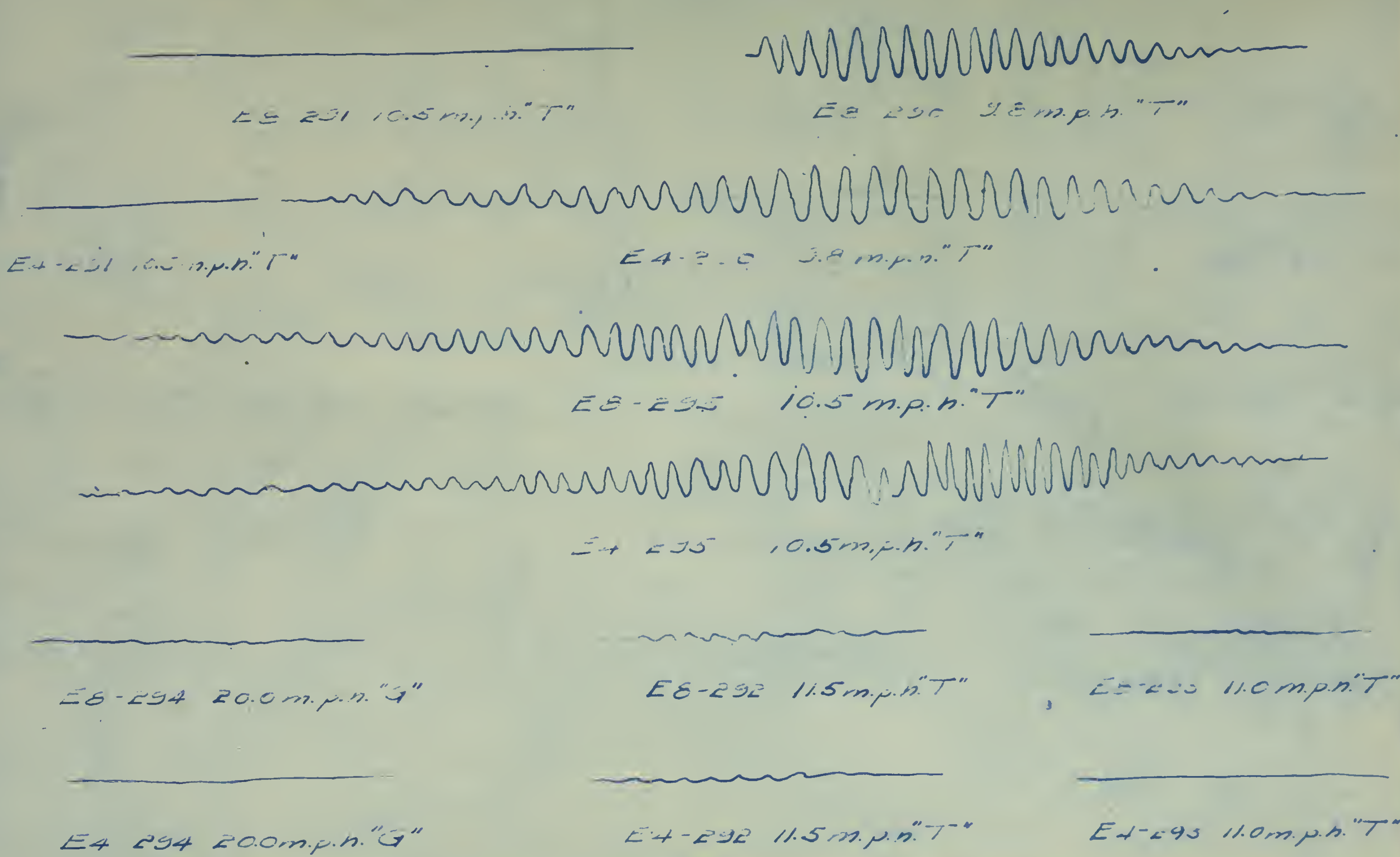


Bridge #6 Span 144' Concrete Floor Load: Horse and Rig

Diagonals U_1L_2 on North and South Trusses

E8 on south truss

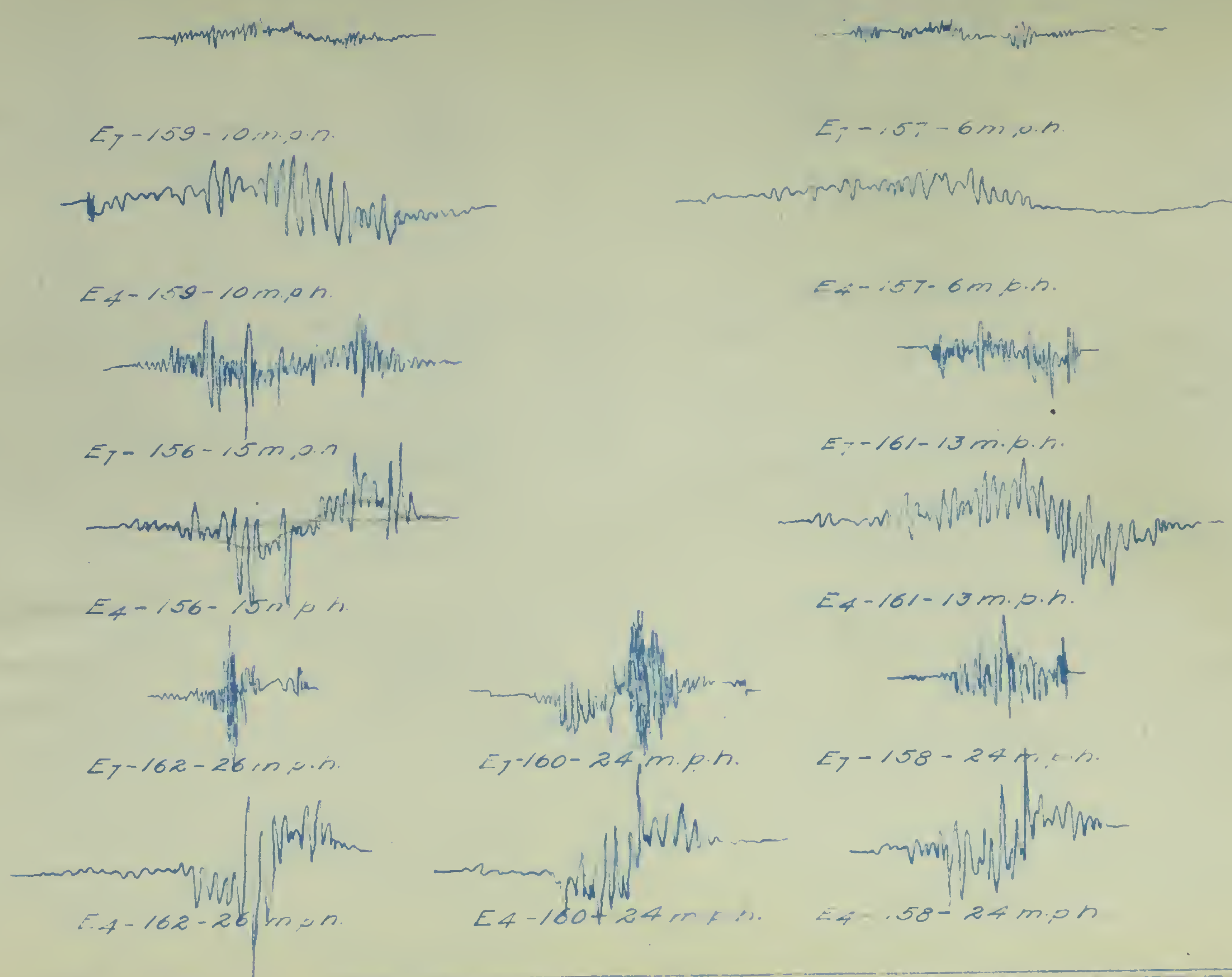
E4 on north truss



b. COUNTERS.

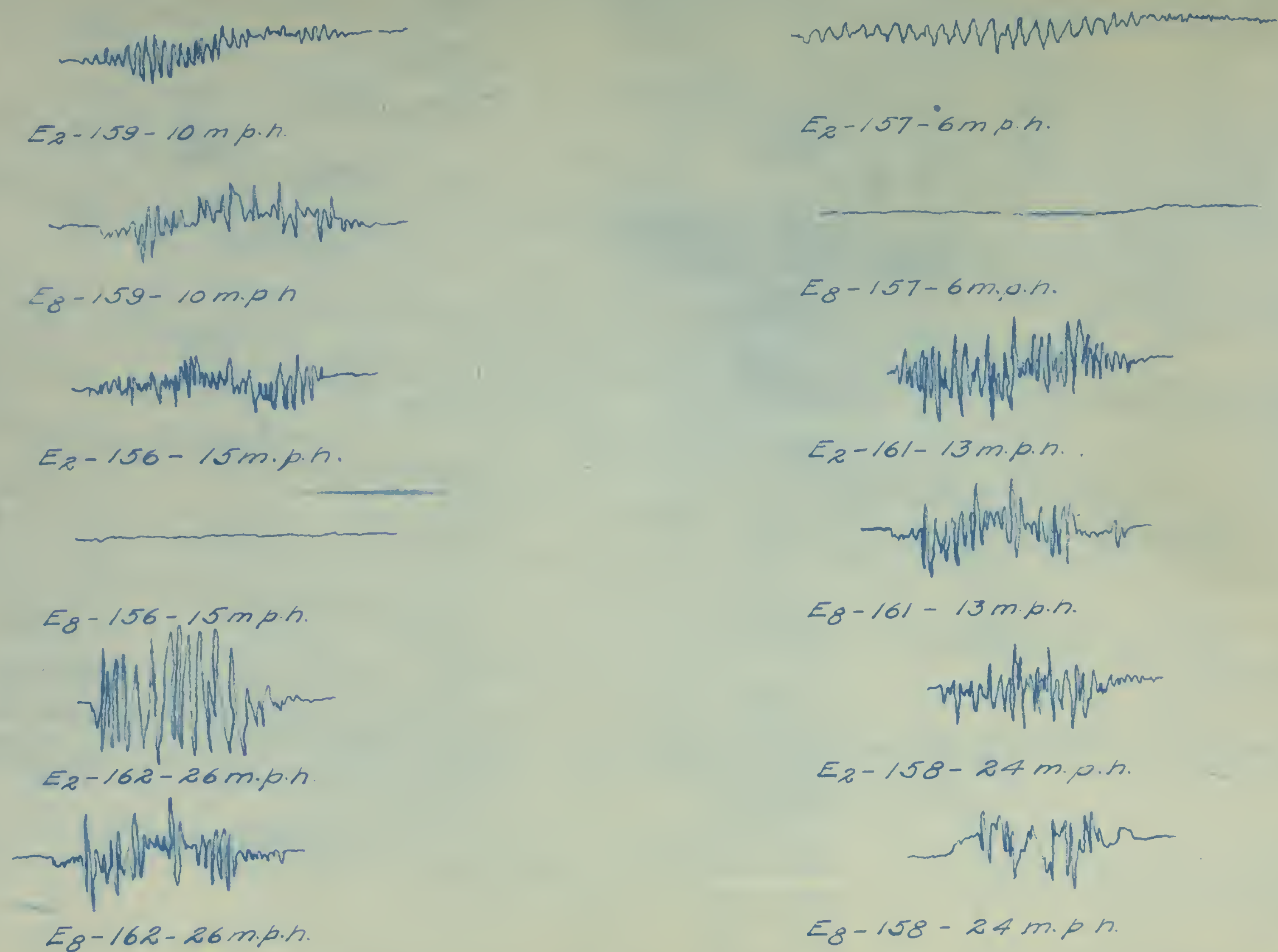
Bridge #2 Counter U_2L_3 E_7 on inside E_4 on outside

Load - Automobile

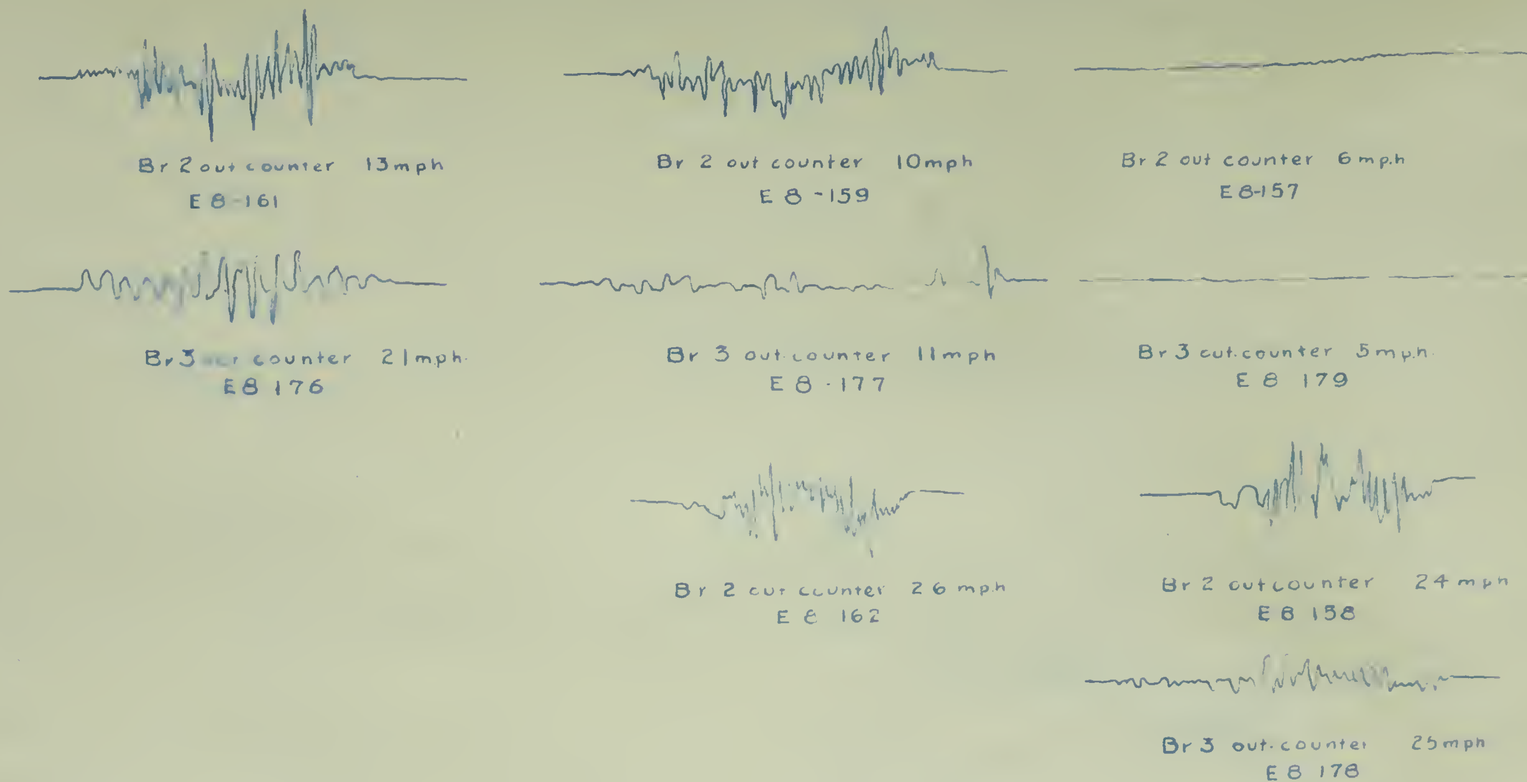


Bridge #2 Counter U_3L_2 E_2 on inside E_8 on outside

Load - Automobile



Diagrams showing effect of automobile on outside counter Br 2 and Br 3 Br 2 plank floor Br 3 concrete floor



Bridge #3. Counters U_2L_3 E_4 inside E_2 outside

Load - "S" - Horse and double seated rig and "D.H" "S" + horse and one seated rig

E_4 - 143 - "D.H" - 15.3 m.p.h "G" E_4 - 142 - "D.H" - 11.2 m.p.h "T" E_4 - 141 - 17.0 m.p.h "G" E_4 - 140 - 9.1 m.p.h "T"

E_2 - 143 - "D.H" - 15.3 m.p.h E_2 - 142 - "D.H" - 11.2 m.p.h "T" E_2 - 141 - 17.0 m.p.h "G" E_2 - 140 - 9.1 m.p.h "T"

Bridge #3 Lower Chord - L_2L_3 E_7 inside E_2 outside

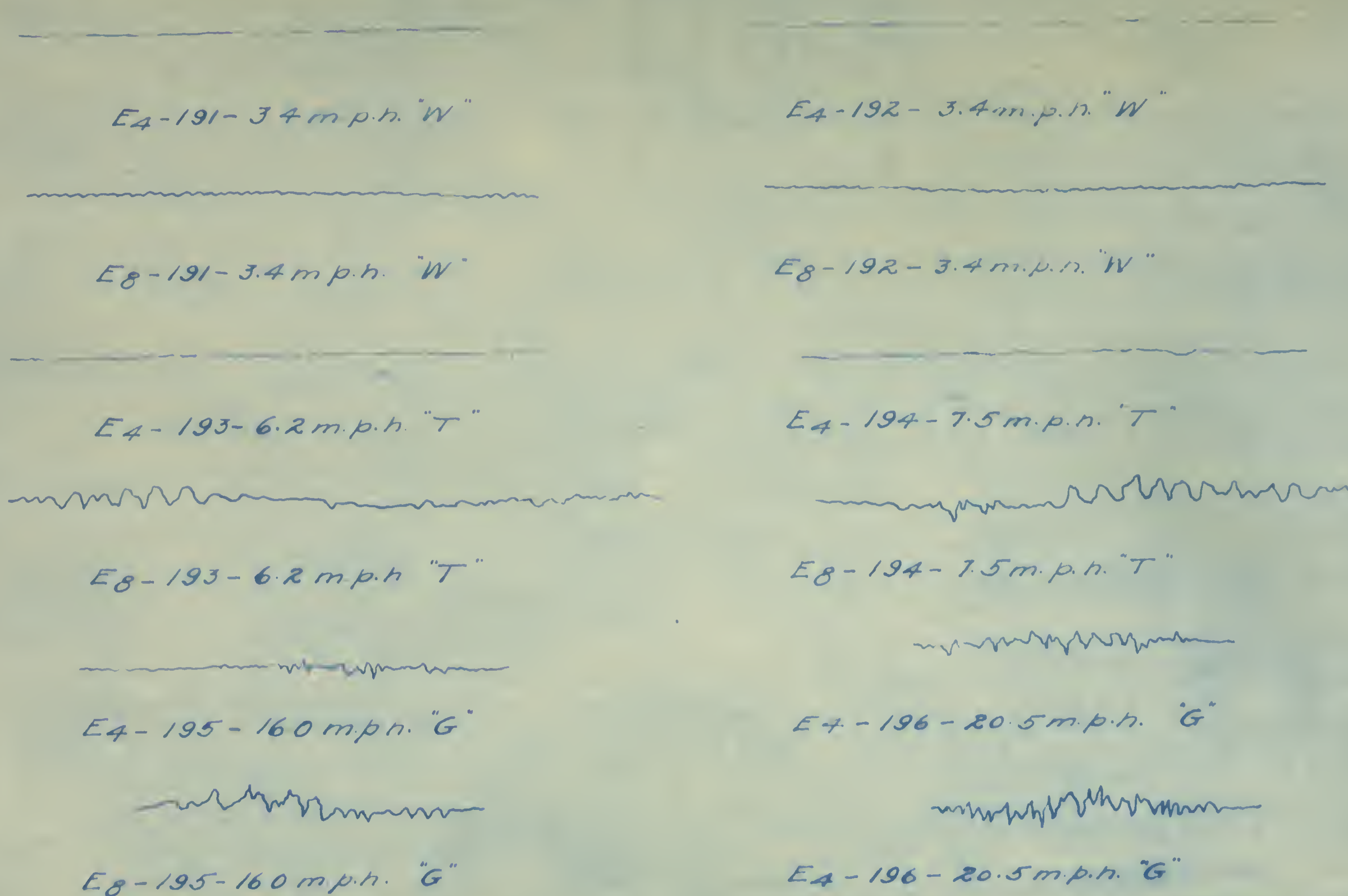
Load - Same

E_7 - 147 - "D.H" - 17.0 m.p.h "G" E_7 - 146 - "D.H" - 10.7 m.p.h "T" E_7 - 145 - 15.3 m.p.h "G" E_7 - 144 - 9.1 m.p.h "T"

E_2 - 147 - "D.H" - 17.0 m.p.h "G" E_2 - 146 - "D.H" - 10.7 m.p.h "T" E_2 - 145 - 15.3 m.p.h "G" E_2 - 144 - 9.1 m.p.h "T"

Bridge #4 - Counter U_3L_2 - E_8 on North truss E_4 on South truss

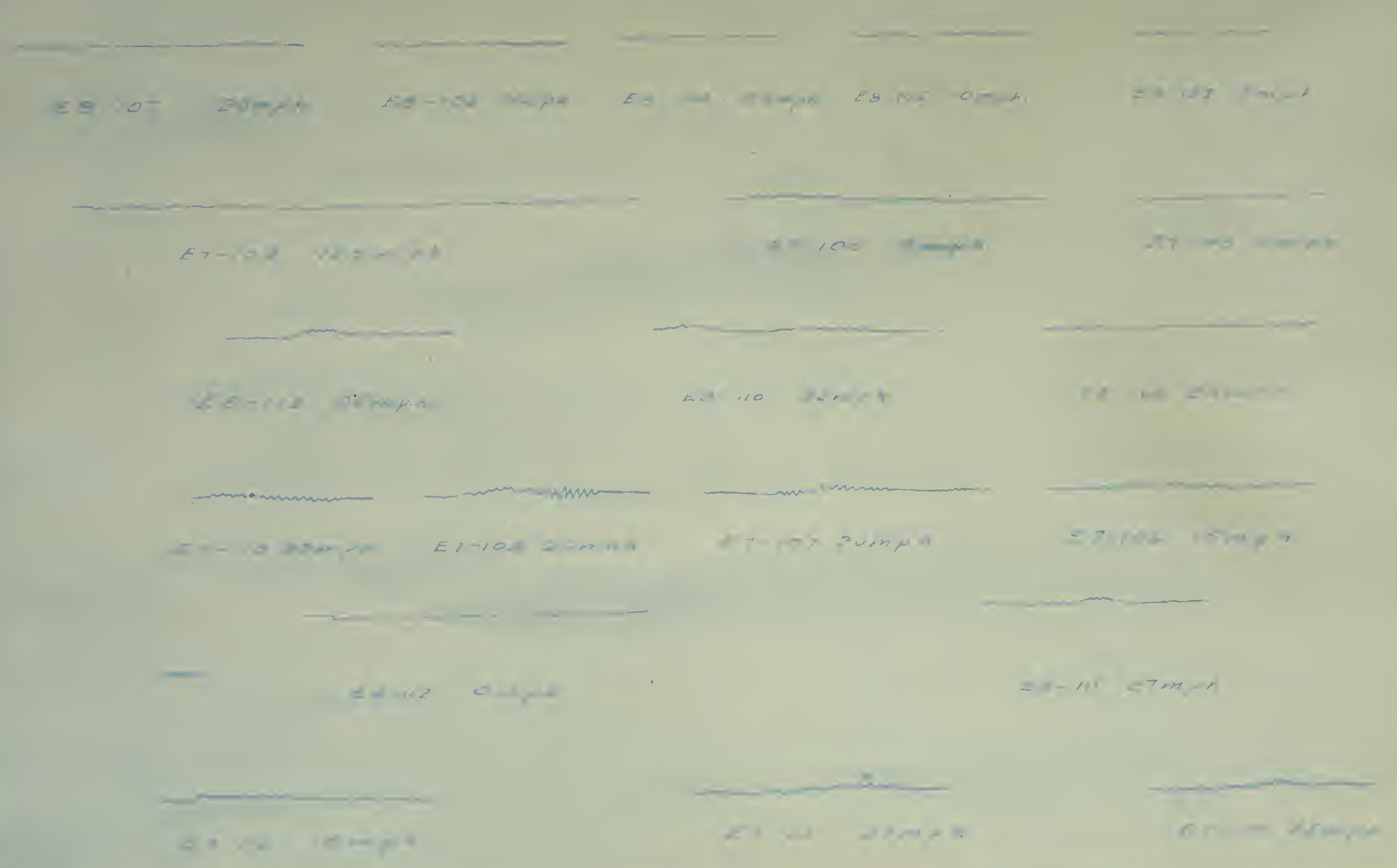
Load - Horse and light double seated rig



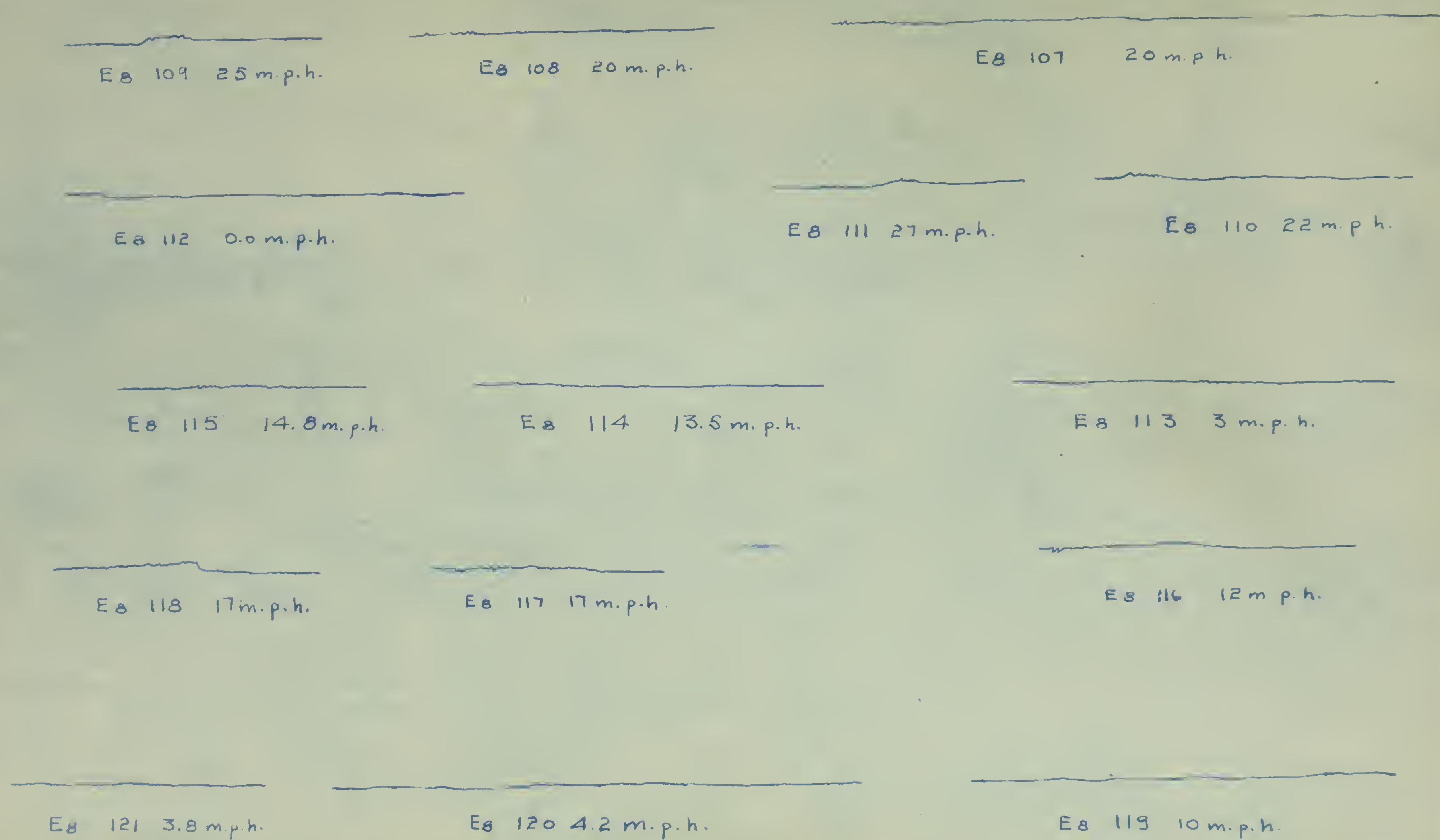
c. HIP VERTICALS.

Bridge #1 Hip Vertical U_3L_3 E_8 on inside bar E_7 on outside bar

Automobile load

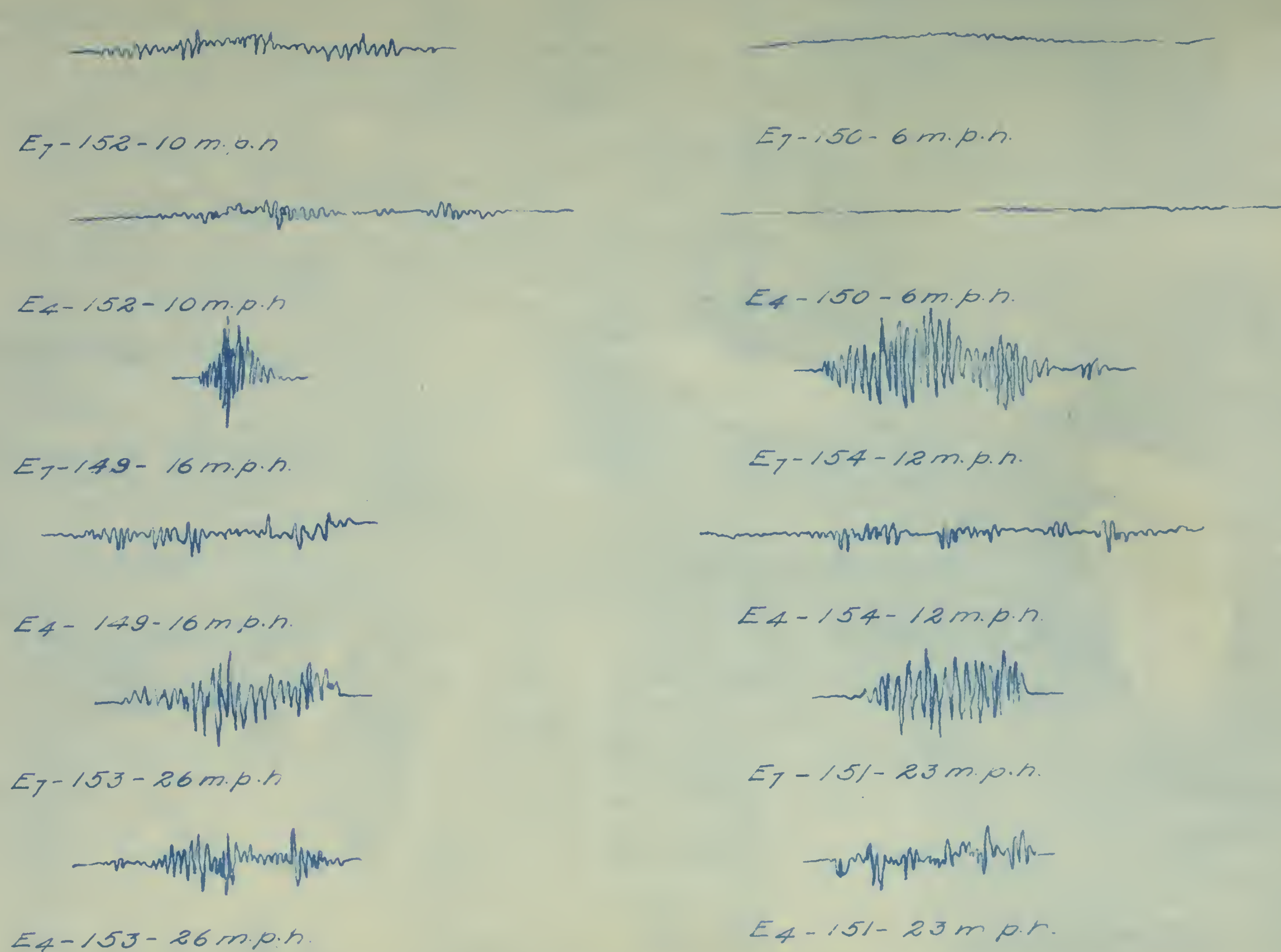


Extensometer on inside hip vertical Br. #1 107-121 Automobile 107-112 Rig 113-121

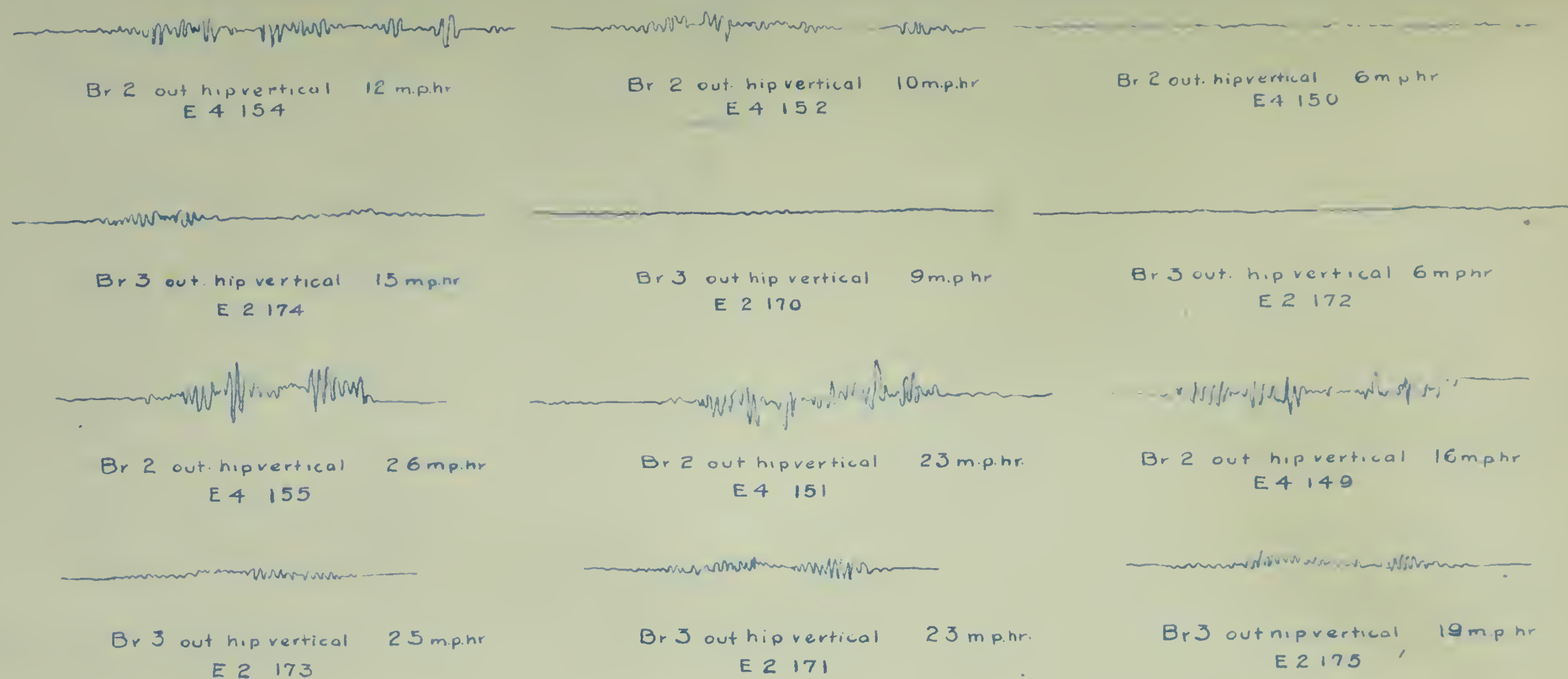


Bridge #2 Hip Vertical U_4L_4 E_7 on inside E_4 on outside

Load - Automobile

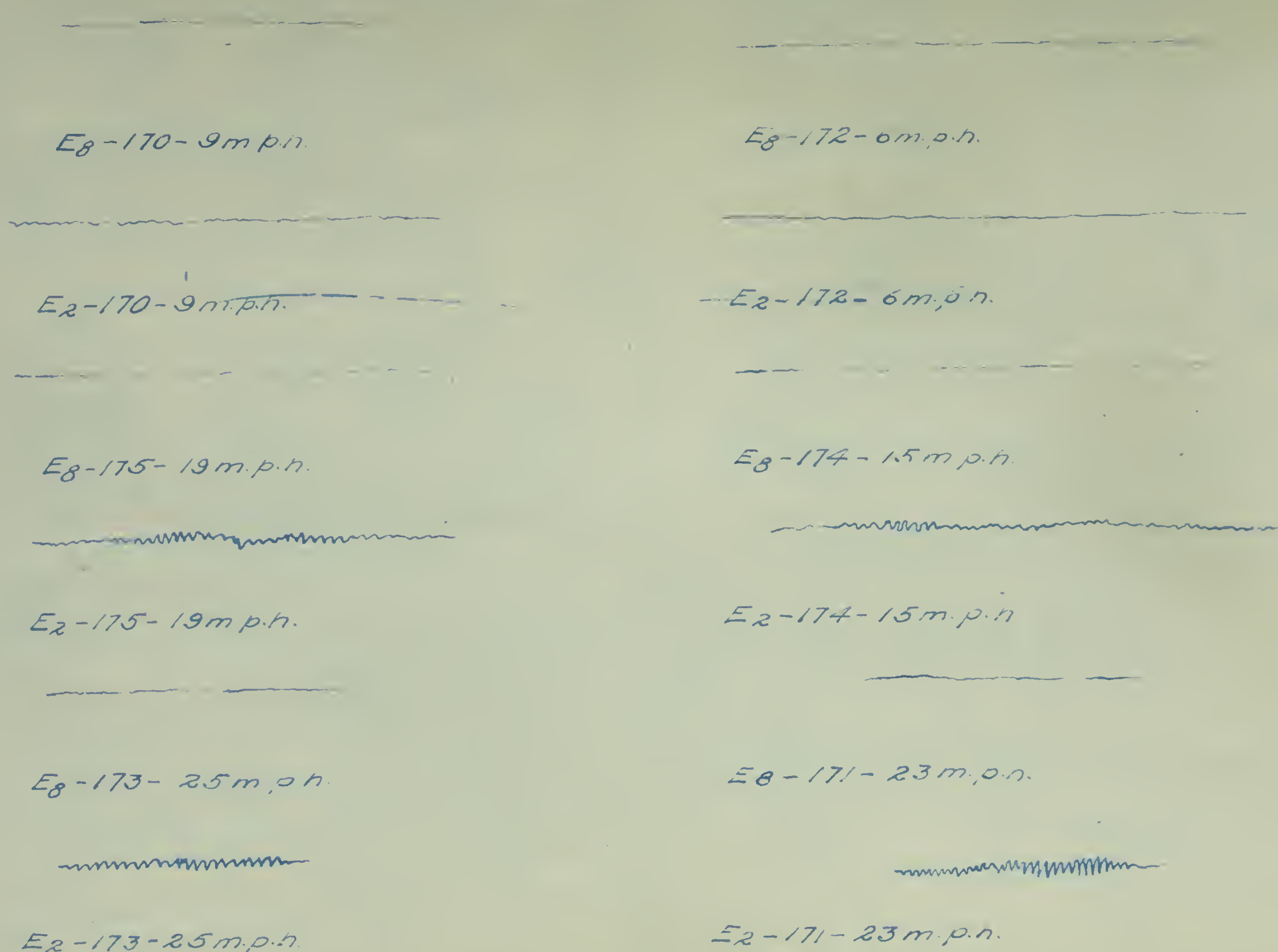


Diagrams showing effect of automobile on Br 2 and Br 3 Br 2 plank floor - Br 3 concrete floor



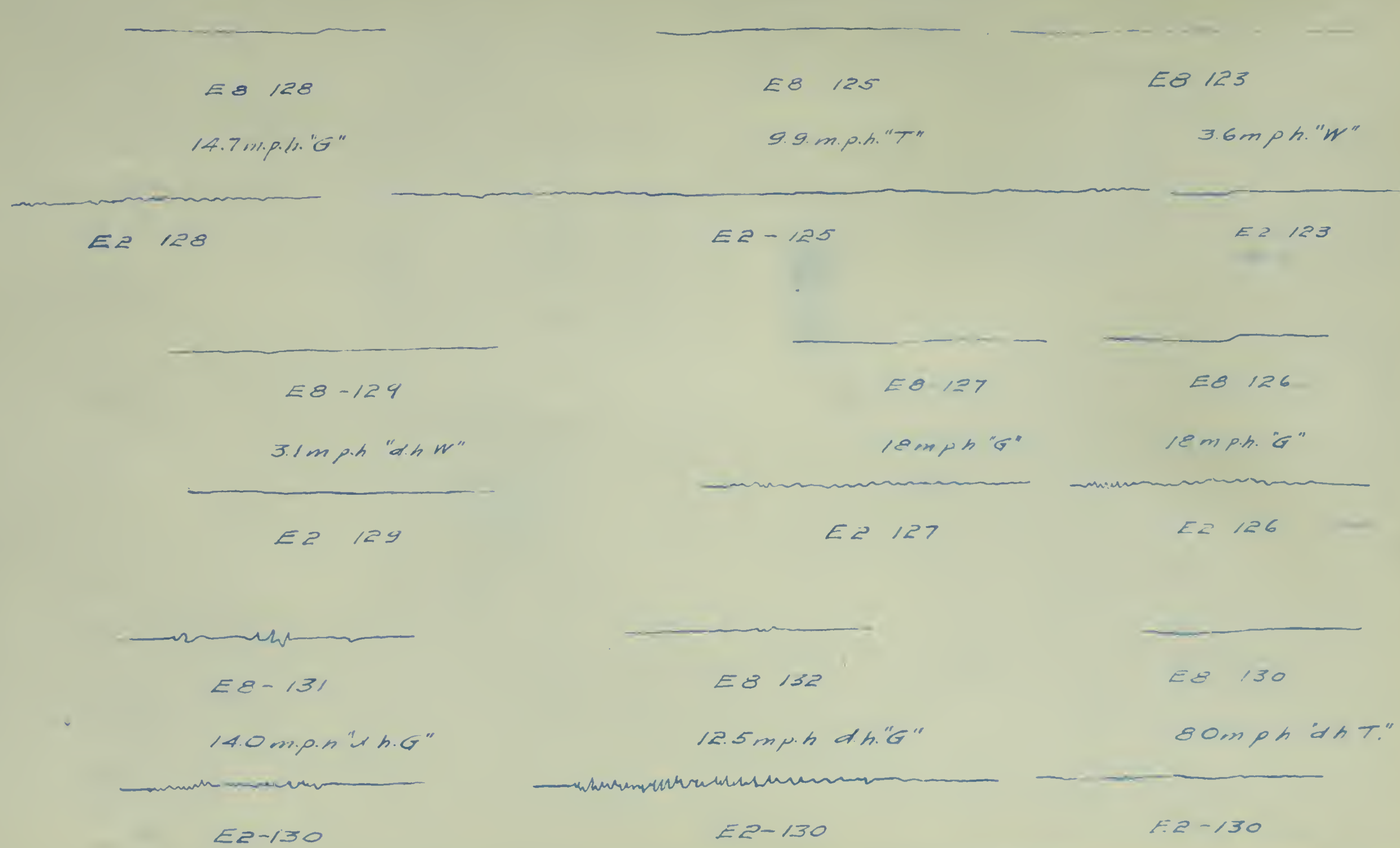
Bridge #3 Hip Vertical U_1L_1 E_8 on inside E_2 on outside

Load-Automobile



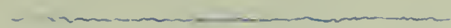
Bridge 3; Span 78'; Concrete floor. Hip Vertical U.L.; E8 on inside, E2 on outside bar

Load { Horse, double seated rig & driver
{ d.h. " " " " " " + same with single rig



Bridge #4 - H p Vertical U_1L_1 - E_7 on inside E_8 on outside
Load- Horse and light double seated rig

E_7 - 185 - 3.4 m.p.h. W



E_8 - 185 - 3.4 m.p.h. "W"

E_7 - 187 - 9.8 m.p.h. "T"

E_8 - 187 - 9.8 m.p.h "T"

E_7 - 189 - 16.1 m.p.h. "G"

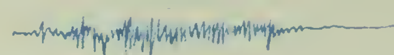
E_8 - 189 - 16.1 m.p.h "G"

E_7 - 186 - 3.4 m.p.h "W"

E_8 - 186 - 3.4 m.p.h. "W"

E_7 - 188 - 5.4 m.p.h "T"

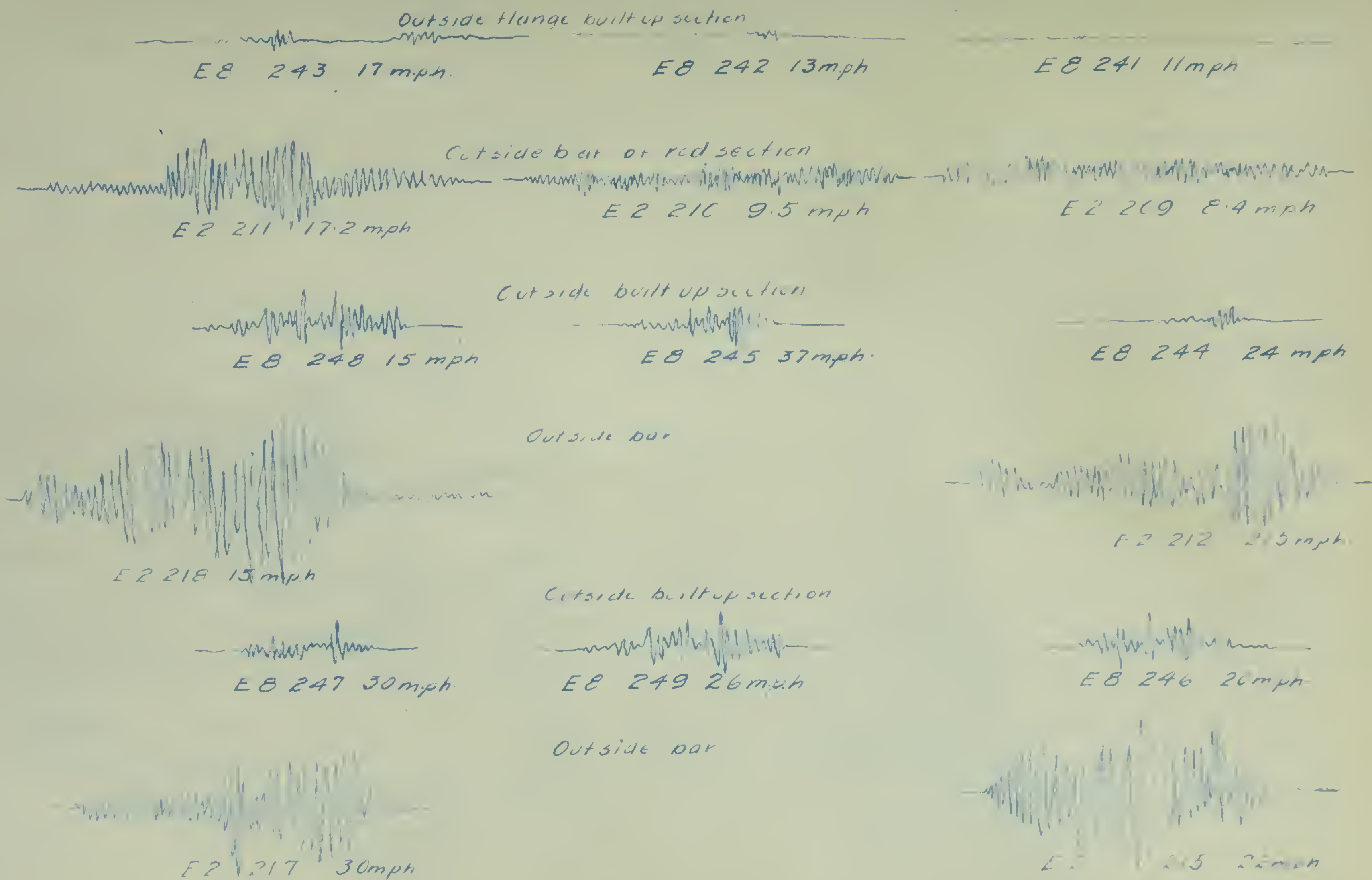
E_8 - 188 - 5.4 m.p.h "T"



E_7 - 190 - 12.0 m.p.h. "G"

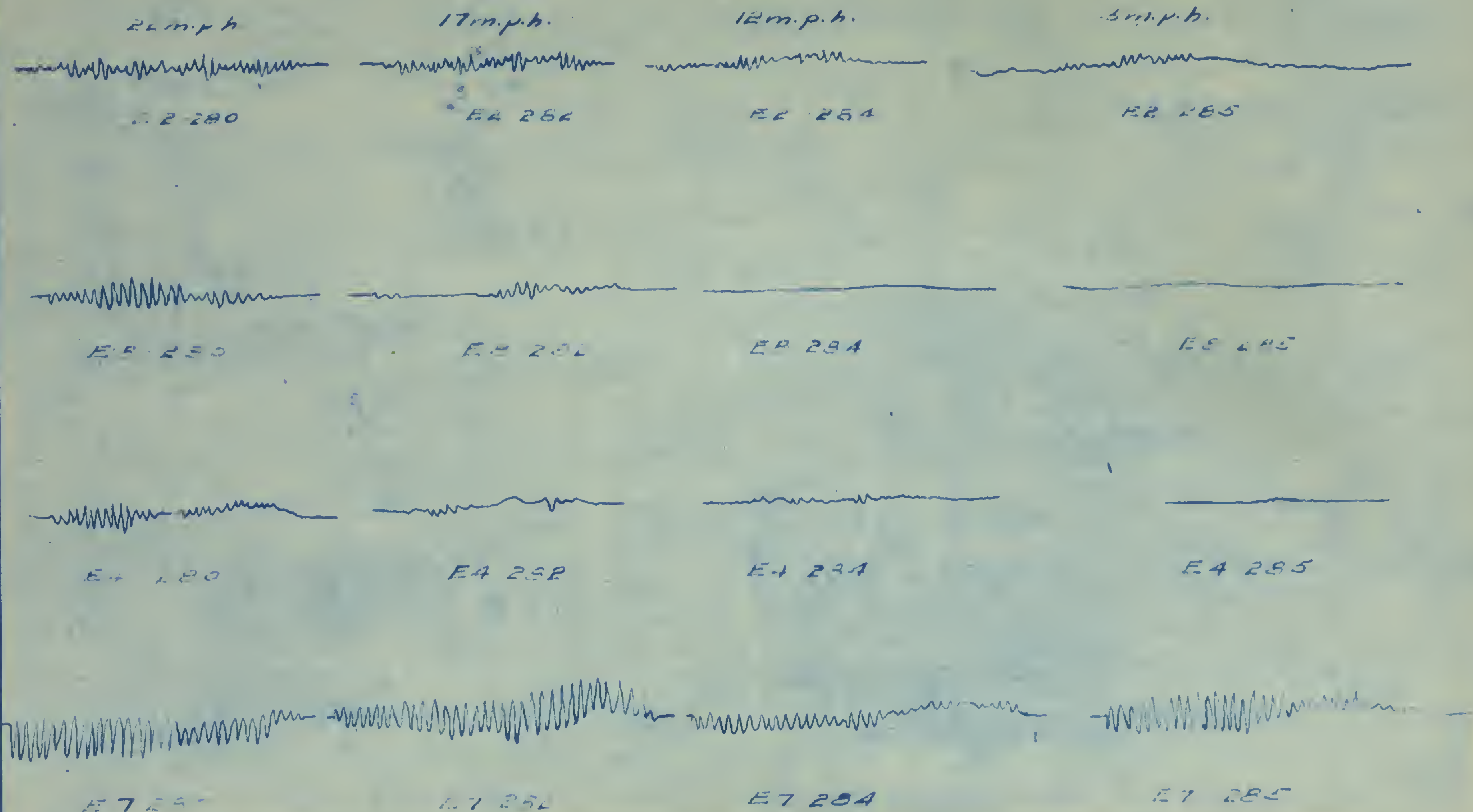
E_8 - 190 - 12.0 m.p.h. "G"

Hip Vertical U.L, Br 5 241-244 209-212 Horse drg 245-249 215-218 Automobile

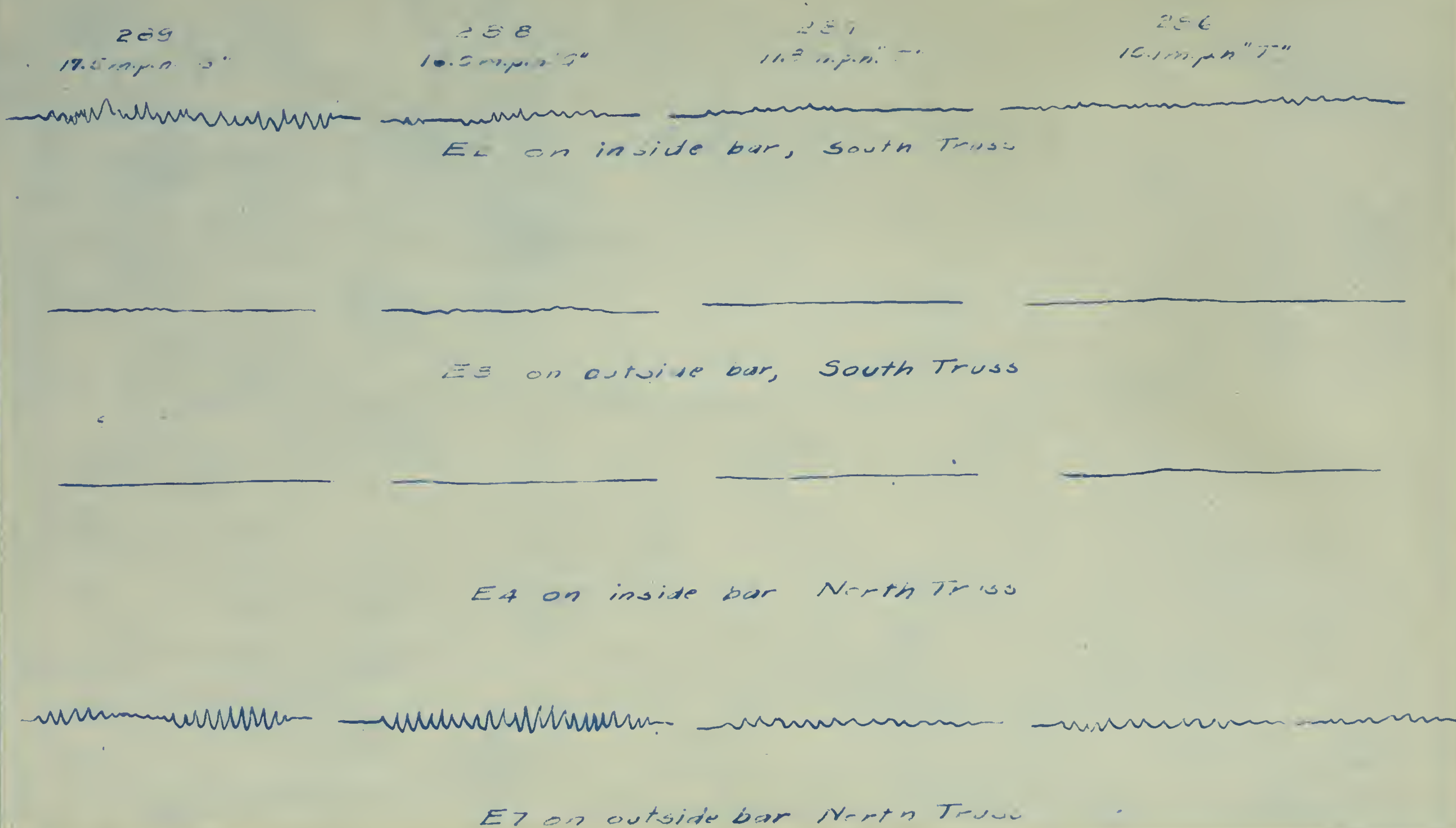


Bridge #6 Span 144' Concrete Floor Hip Vertical L_1U_1 Load: Automobile

E2 on inside bar So. truss; E8 on outside bar. E4 on inside, E7 on outside bar north truss



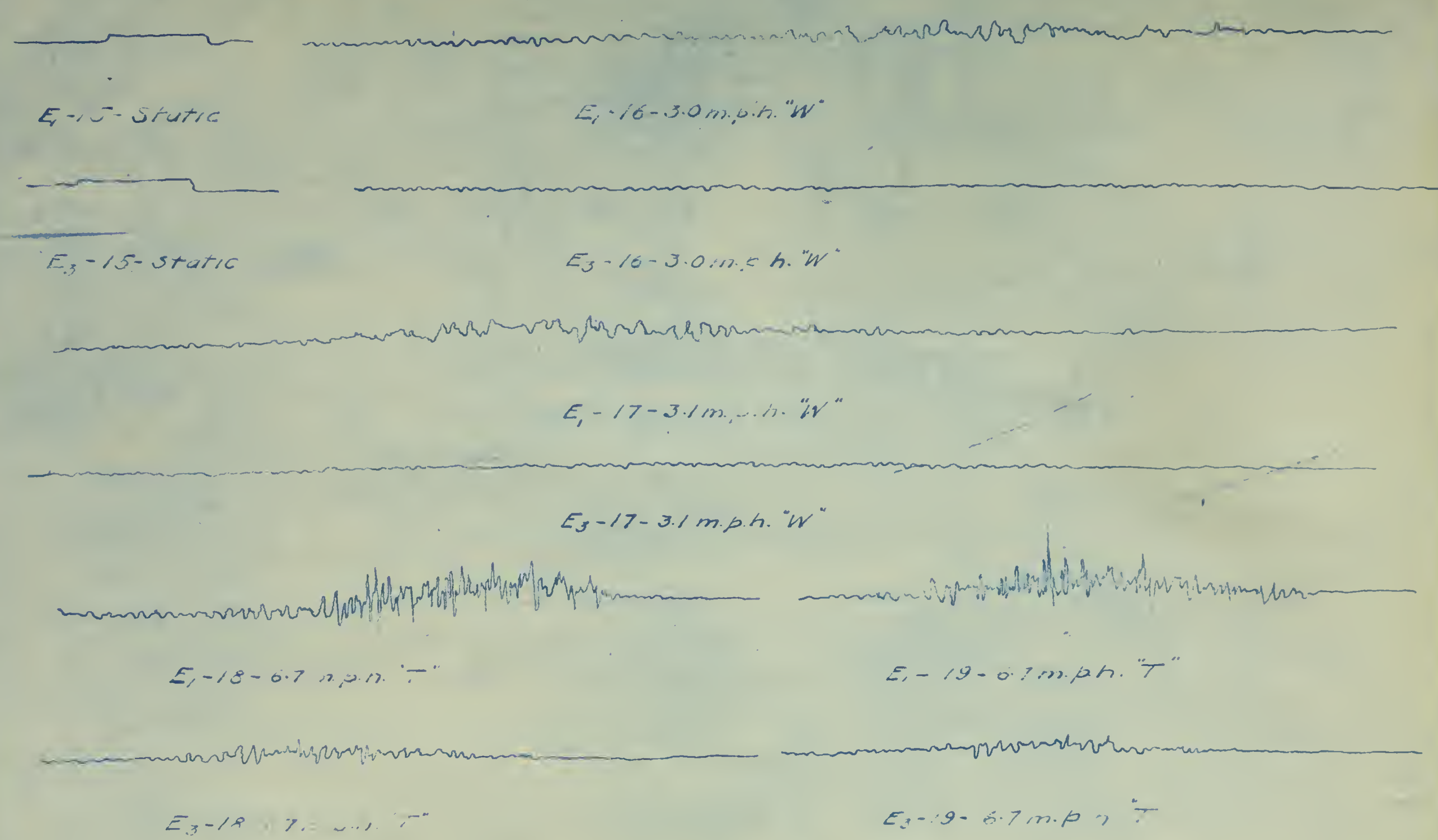
Bridge #6 Span 144' Concrete Floor Hip Vertical L, U, Load: Horse and Rig

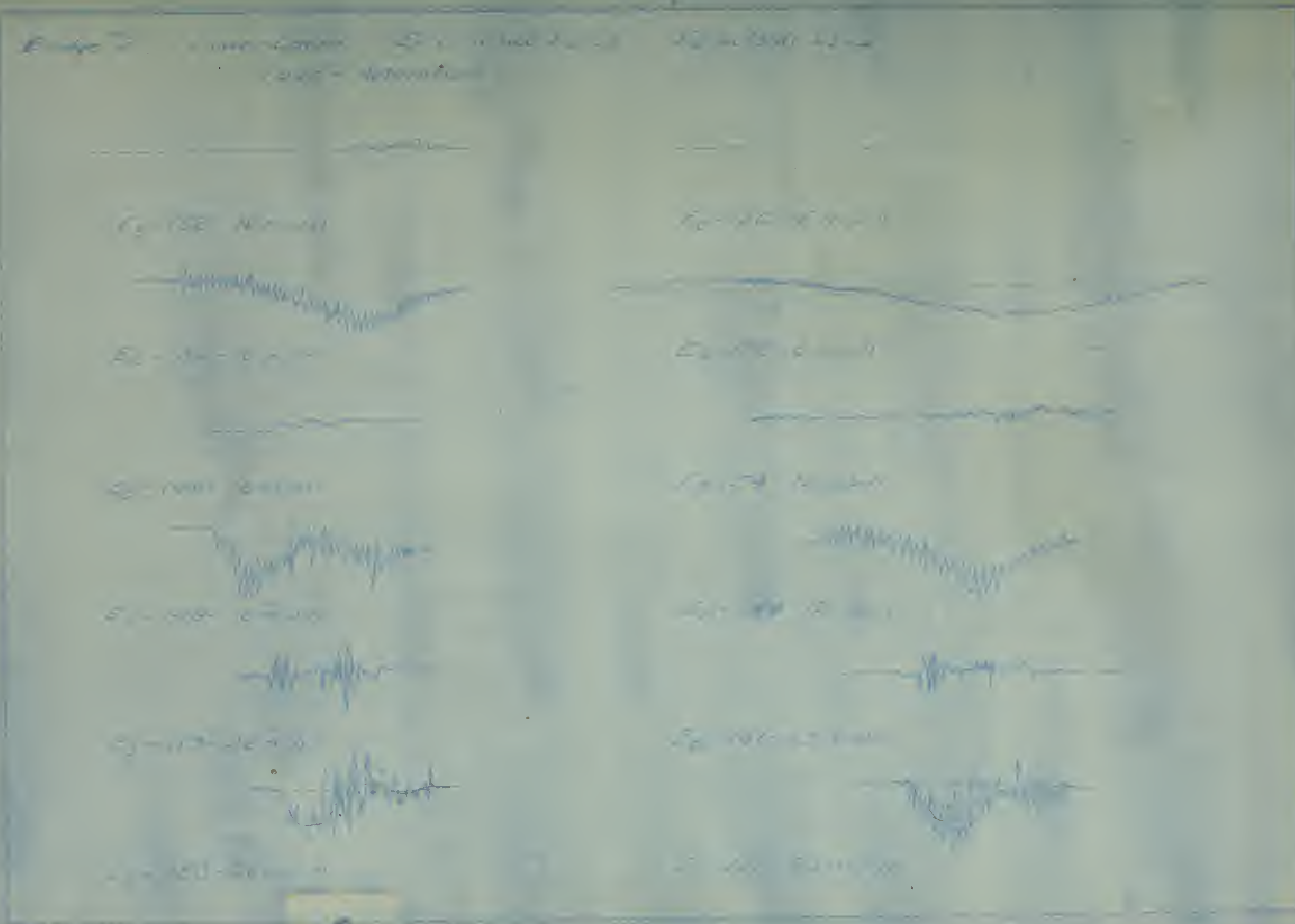


d. LOWER CHORDS.

Bridge #1 Lower Chord $L_2 L_3$ E_1 on inside E_3 on outside From Thesis 1909

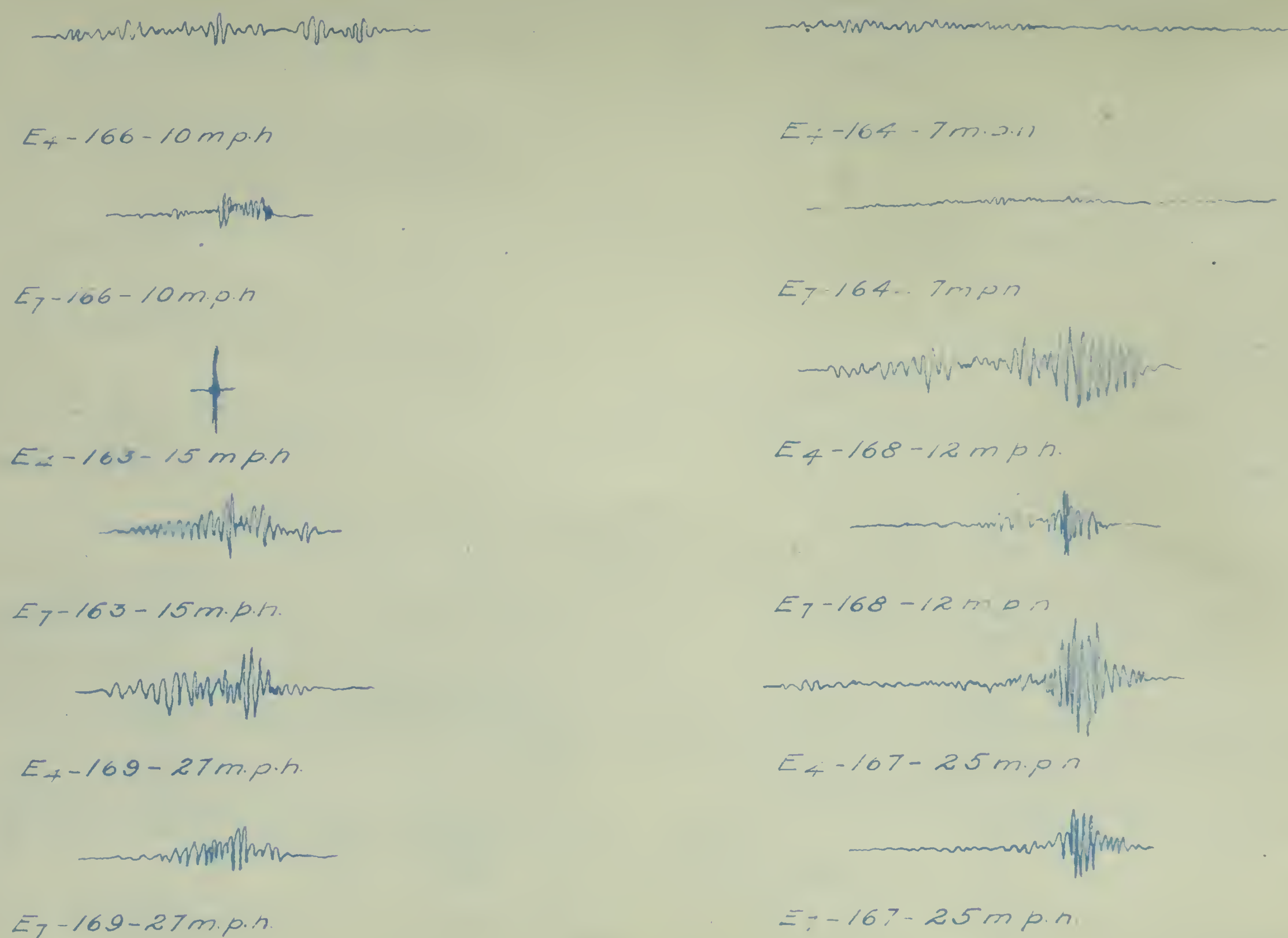
Load - Lumber Wagon





Bridge #2 Lower Chord L_2L_3 E_4 on outside of west truss E_7 on outside of east truss

Load- Automobile



Bridge #3 Lower chord L.?. E8 inside E2 outside

Load - 5-Horse and Two seated rig and I ?. 5 horse and ? seated rig

E8-134-95 m.p.h. F — E8-133-85 ...

E2-34 ...

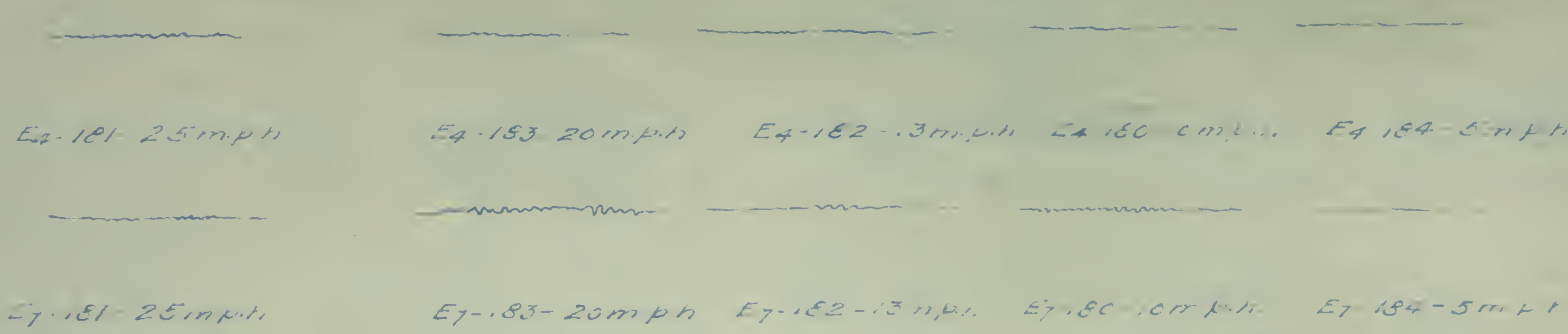
E8-136-180 m.p.h. G — E8-135- ... G

E2-136 80 m.p.h. G — E2-135-125 ...

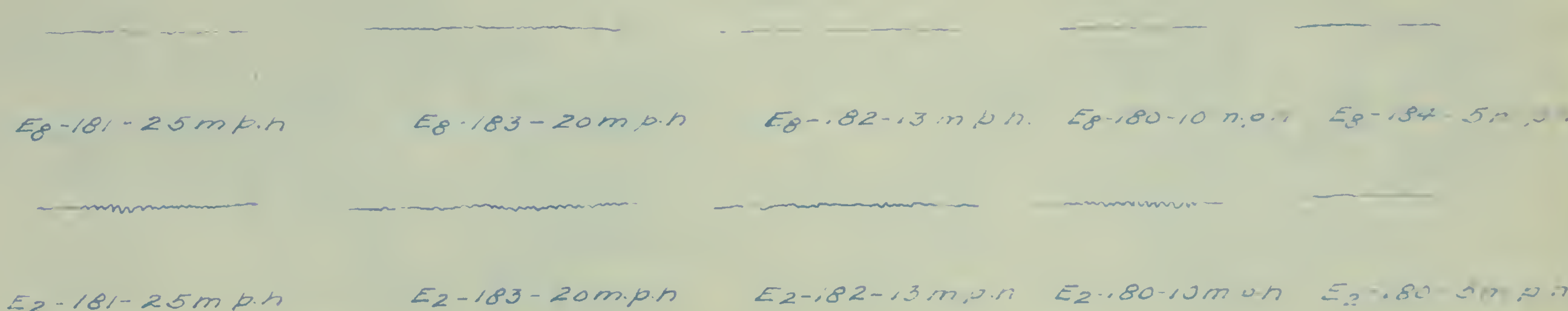
E8-139-I4-...F — E8-138-... — E8-13?-...

E2-139-... — E2-138-... — E2-13?-...

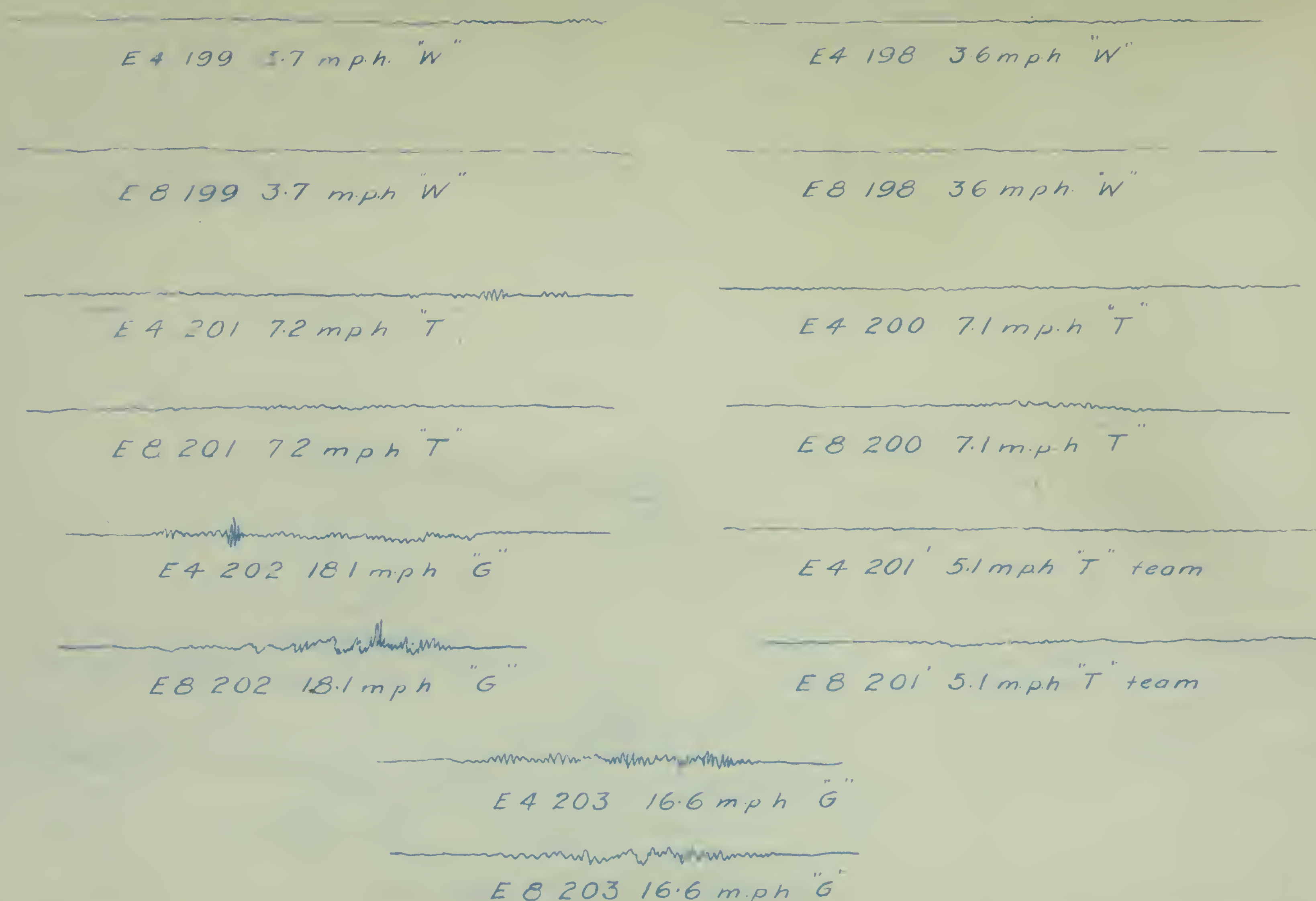
Bridge #3 Lower Chord L_2L_3 E_4 on N. truss E_7 on S. truss
Load - Automobile



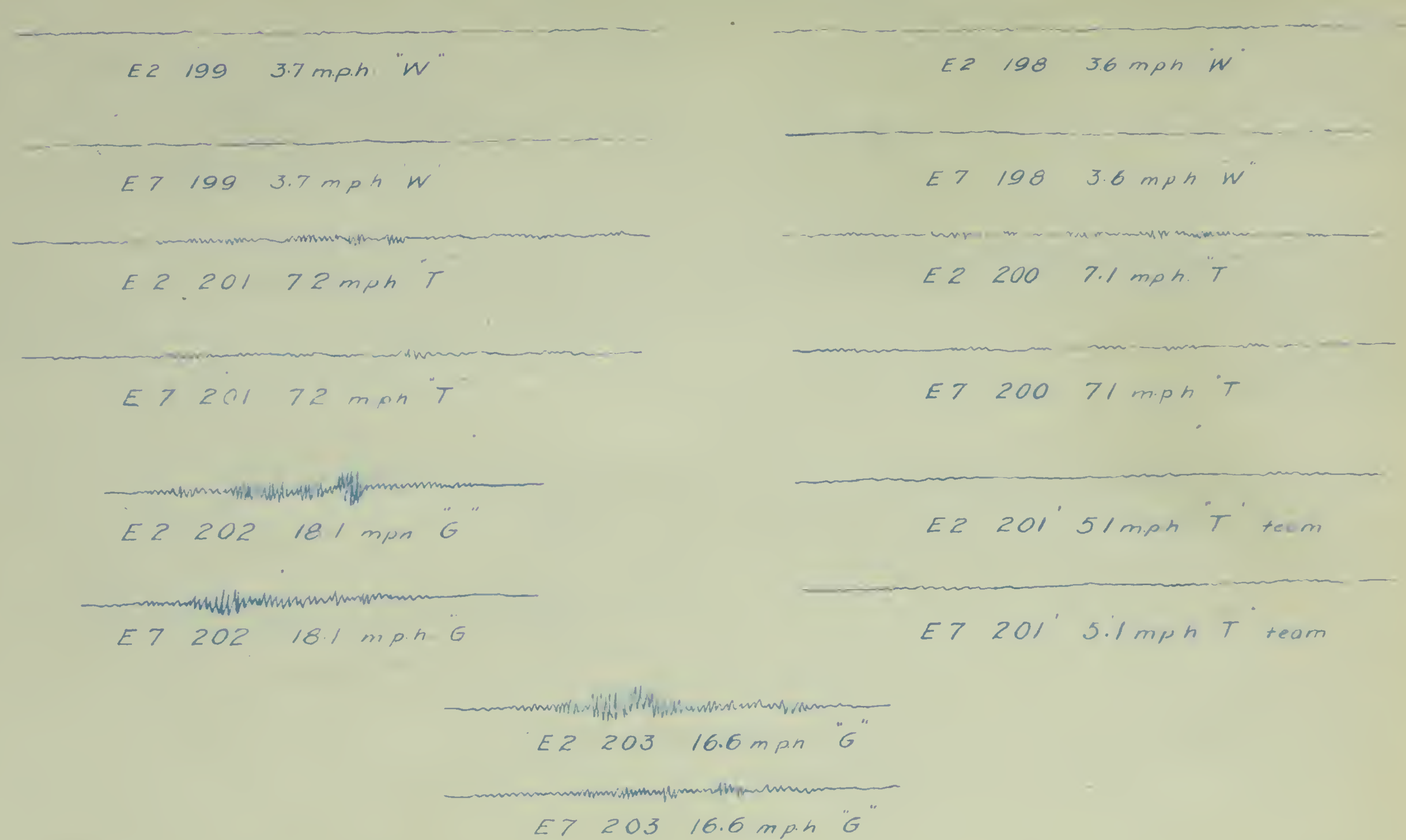
Bridge #3 Lower Chord L_1L_2 E_8 on N. truss E_2 on S. truss
Load - Same



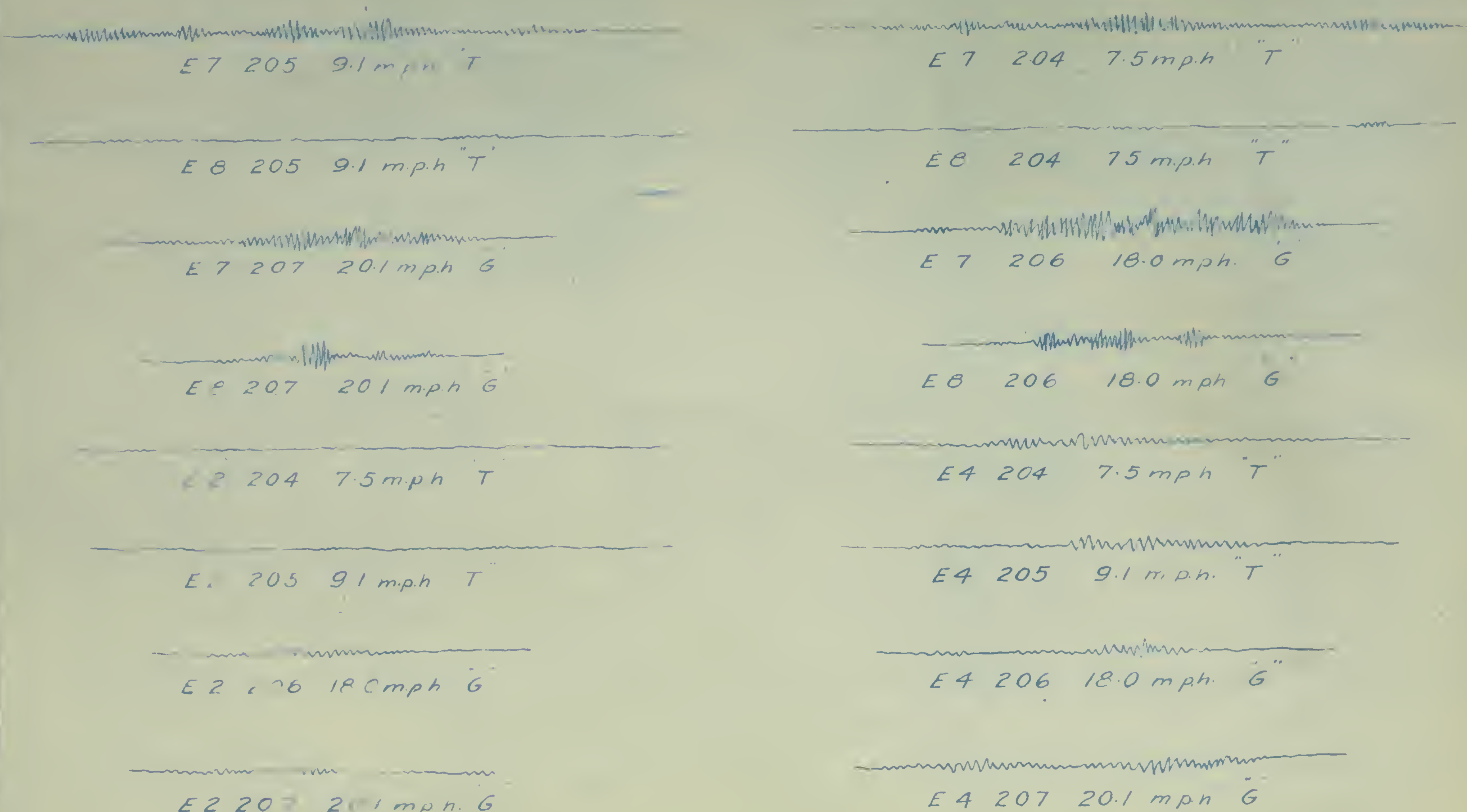
Bridge #4 Bottom Chord $L_1 L_2$ E 4 inside E8 outside Load - Horse and 2 seated rig



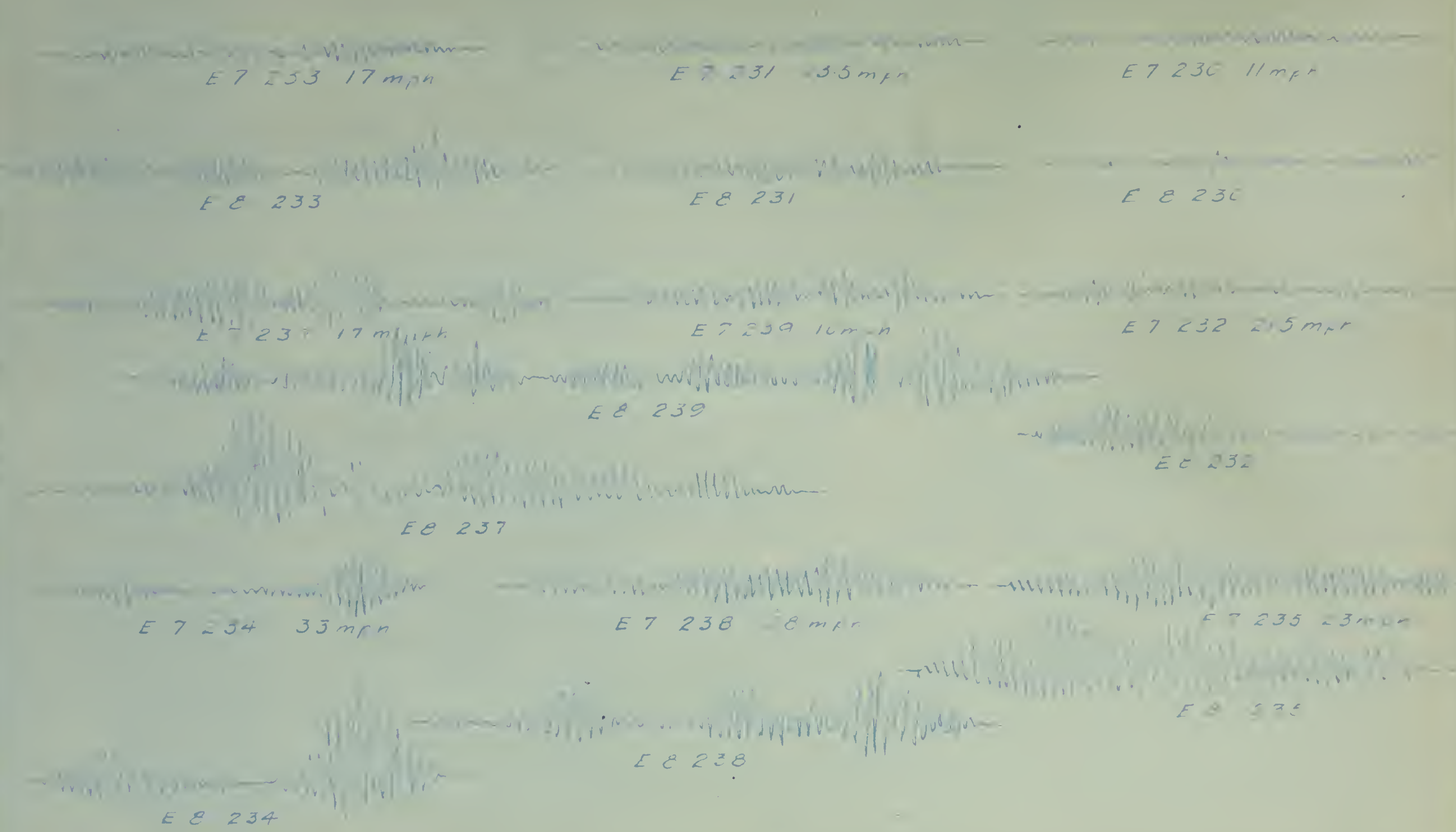
Bridge #4 . Bottom Chord $L_2 L_3$ E 2 inside E 7 outside Load - Horse and 2 seated rig



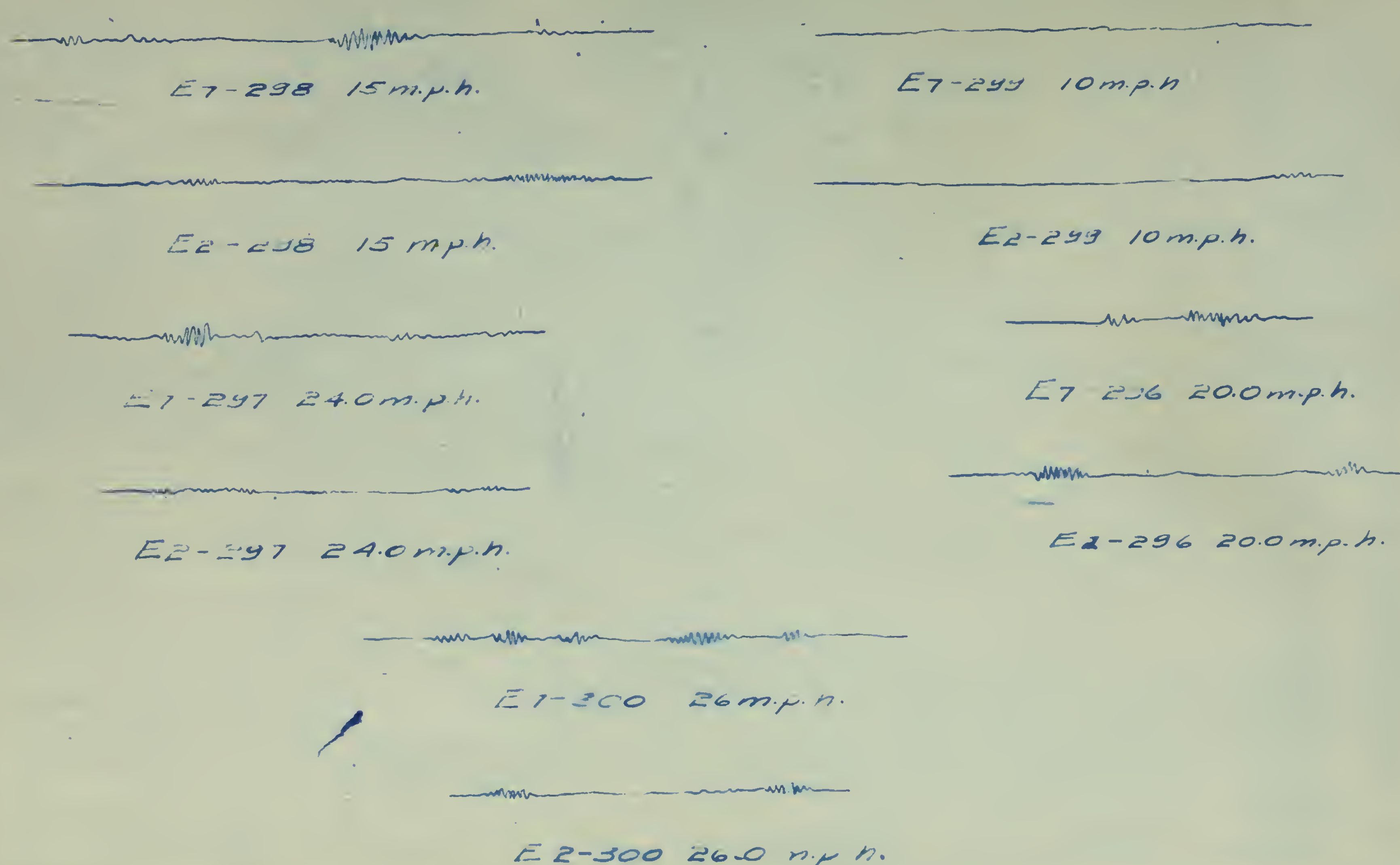
Bridge # 4 Bottom Chord E 7 on outside L_3L_4 north truss E 8 on outside L_3L_4 south truss
E 2 on outside L_2L_3 south truss E 4 on outside L_1L_2 south truss Load Horse and 2 seated rig



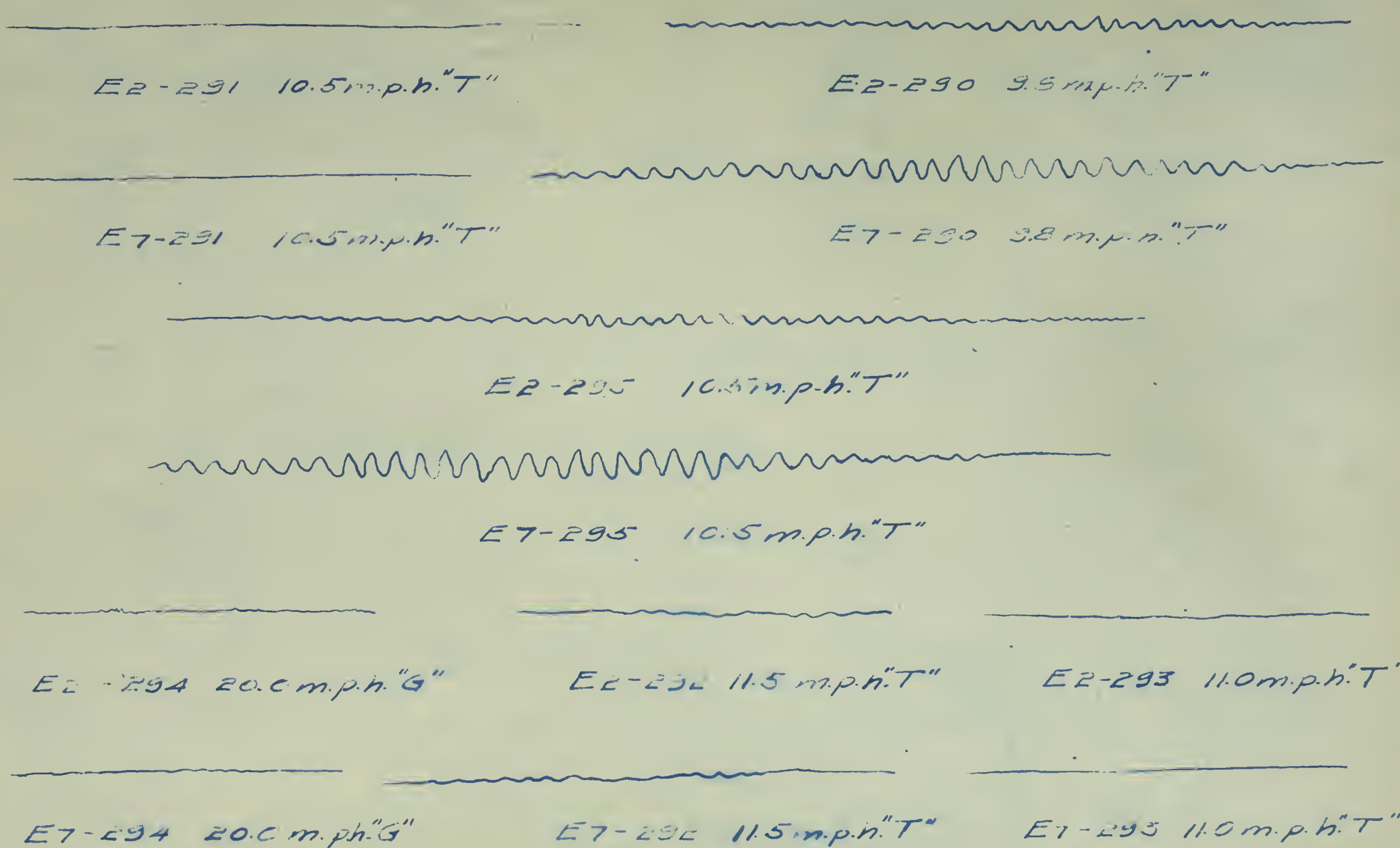
Lower chord L_0L_1 E 7 cut [illegible] W truss ; [illegible] bar E truss 230-33 [illegible] 234 239 [illegible]



Bridge #6 Span 144' Concrete Floor Load - Automobile
Lower Chord L_1L_2 E7 on north truss E2 on south truss



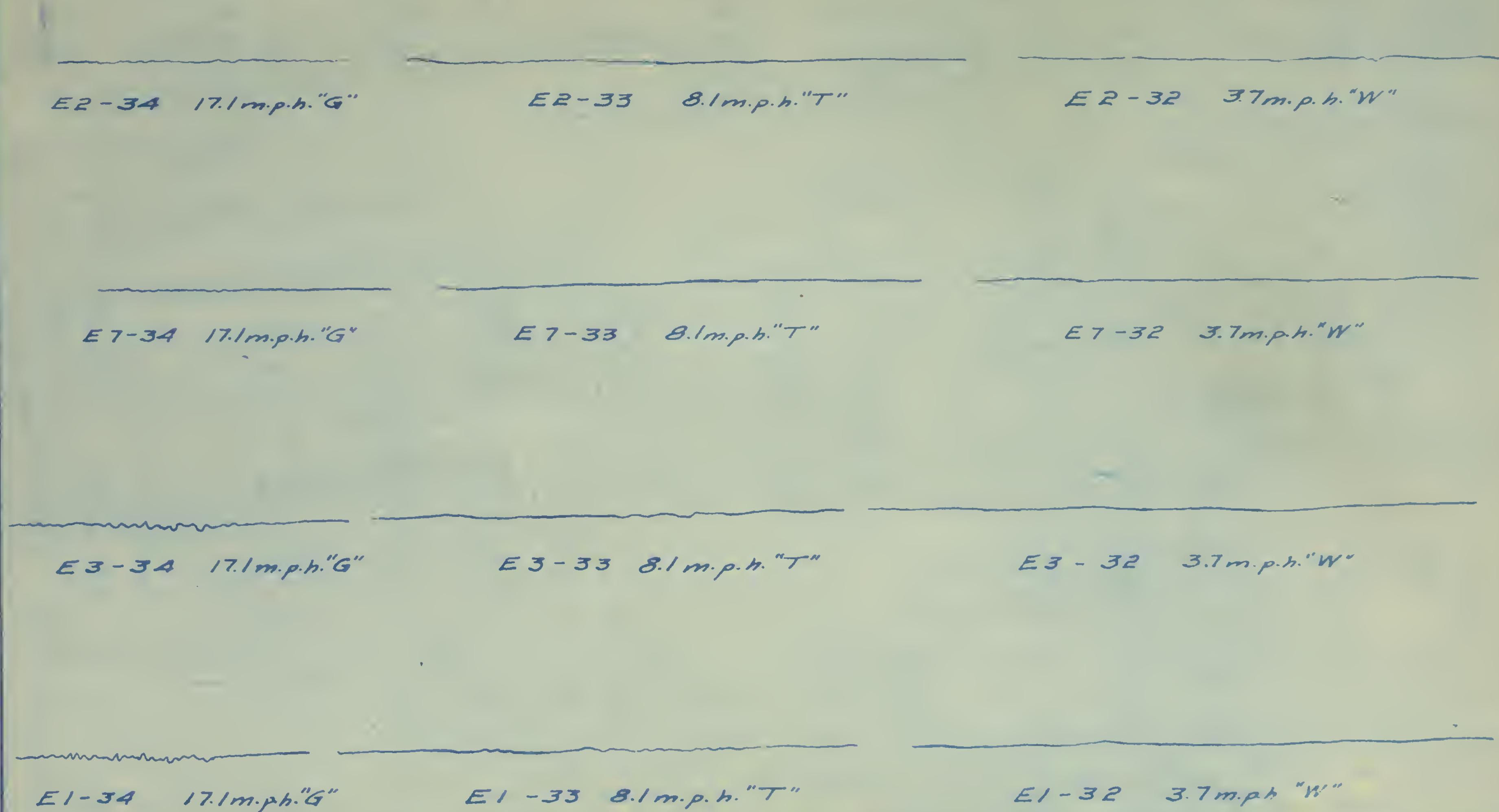
Bridge #6 Span 144' Concrete Floor Load: Horse and Rig
Bottom Chords $L_1 L_2$ E2 on south Truss E7 on north Truss



a. END POSTS.

Bridge #1 Span 55' End Post L_0U_1 Load:- Horse and Rig

E_2 on top inside flange. E_7 on bottom inside flange. E_3 on top outside flange. E_1 on bottom outside flange



Bridge #2 Span 70' End Post L_oU_1 Loads:- Horse & Rig, 44-48; Team & Lumber Wagon 66-68

E1 on inside upper flange E7 on outside upper flange

E1-48 13.6 m.p.h. "G"

E1-46 9 8 m.p.h. "T"

E1-44 2.9 m.p.h. "W"

E7 48 13.6 m.p.h. "G"

E7-46 9.8 m.p.h. "T"

E7-44 2.9 m.p.h. "W"

E1-68 17 0 m.p.h. "G"

E1-67 8.5 m.p.h. "T"

E1-66 3.4 m.p.h. "W"

E1-68 17.0 m.p.h. "G"

E7-61 8.5 m.p.h. "T"

E7-66 3.4 m.p.h. "W"

b. INTERMEDIATE POSTS.

Bridge #2 Int. Post. U_2L_2 E_2 on south [E_8 on north [

Load - Automobile

E_2-166-10 m.p.h.

E_8-166-10 m.p.h

E_2-163-15 m.p.h

E_8-163-15 m.p.h.

E_8-169-27 m.p.h.

E_2-164-7 m.p.h.

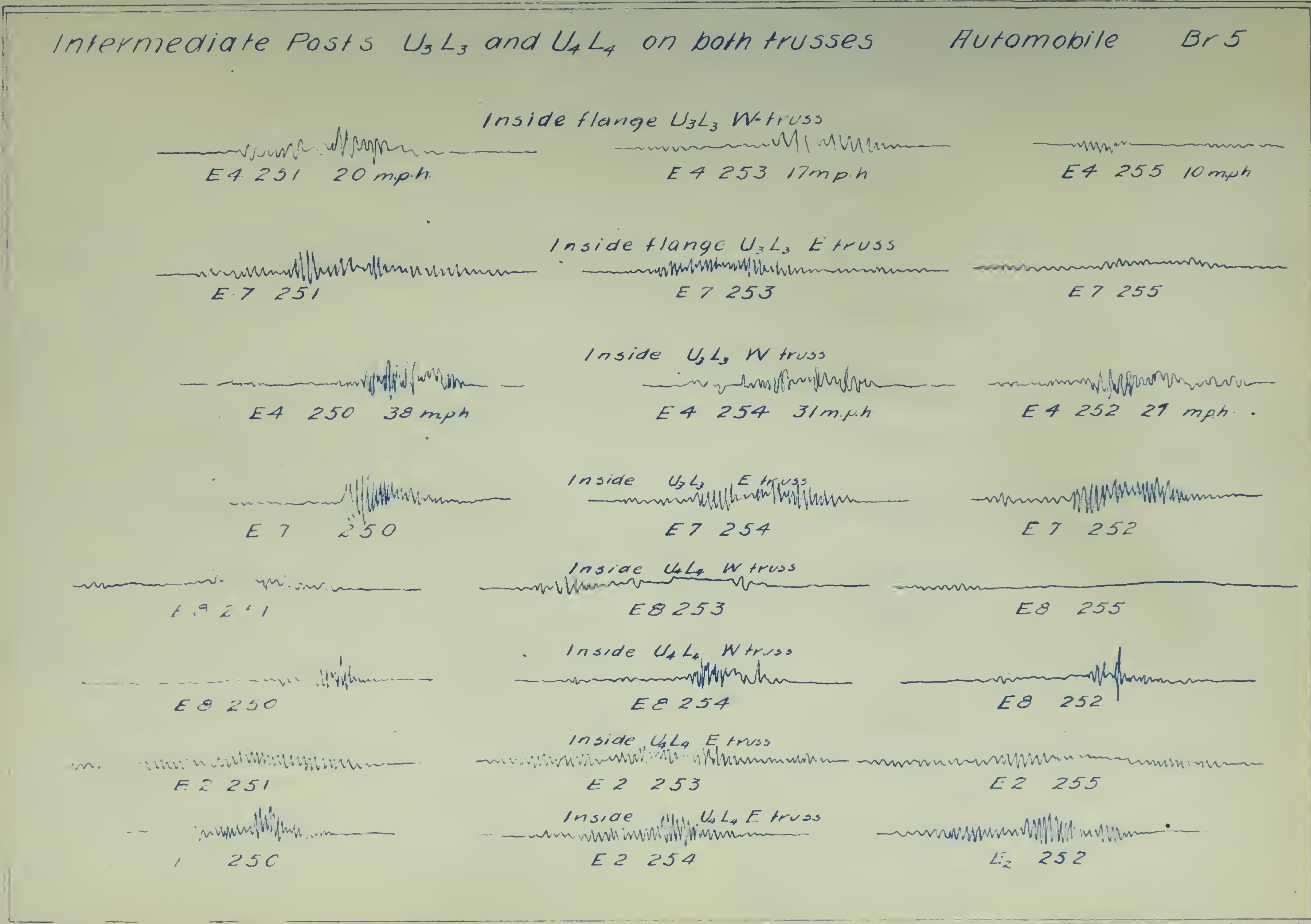
E_8-164-7 m.p.h.

E_2-168-12 m.p.h.

E_8-168-12 m.p.h.

E_2-167-25 m.p.h.

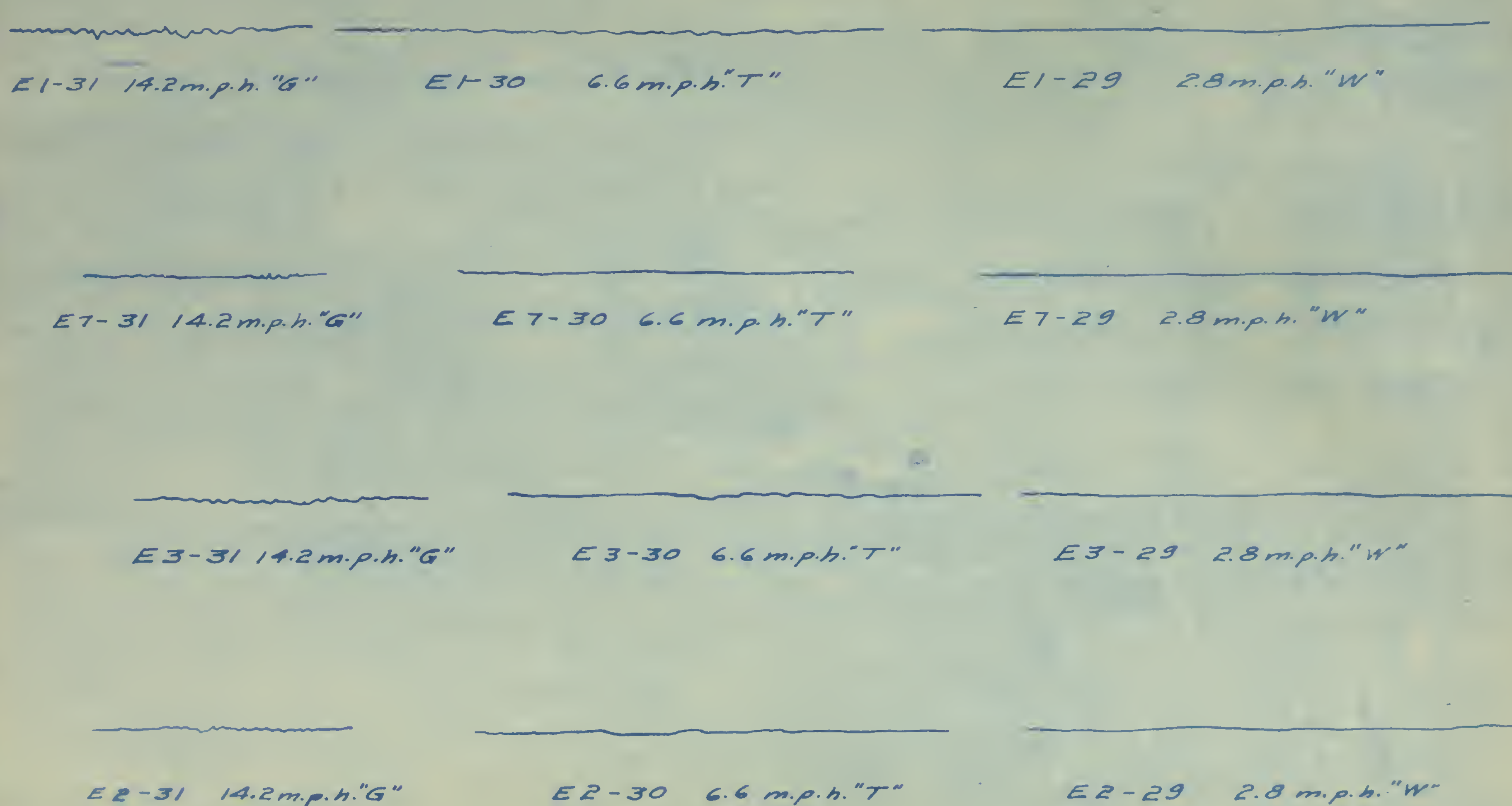
E_8-167-25 m.p.h


Intermediate Posts U_3L_3 and U_4L_4 on both trusses Automobile Br 5
Inside flange U_3L_3 W-truss
E4 251 20 m.p.h.
E 4 253 17 m.p.h
E4 255 10 mph
Inside flange U_3L_3 E truss
E 7 251
E 7 253
E 7 255
Inside U_3L_3 W truss
E4 250 38 mph
E 4 254 31 m.p.h
E 4 252 27 mph
Inside U_3L_3 E truss
E 7 250
E7 254
E 7 252
Inside U_4L_4 W truss
E8 253
E8 255
Inside U_4L_4 W truss
E 8 250
E8 254
E8 252
Inside U_4L_4 E truss
E 2 251
E 2 253
E2 255
Inside U_4L_4 E truss
250
E 2 254
E_2 252

c. UPPER CHORDS.

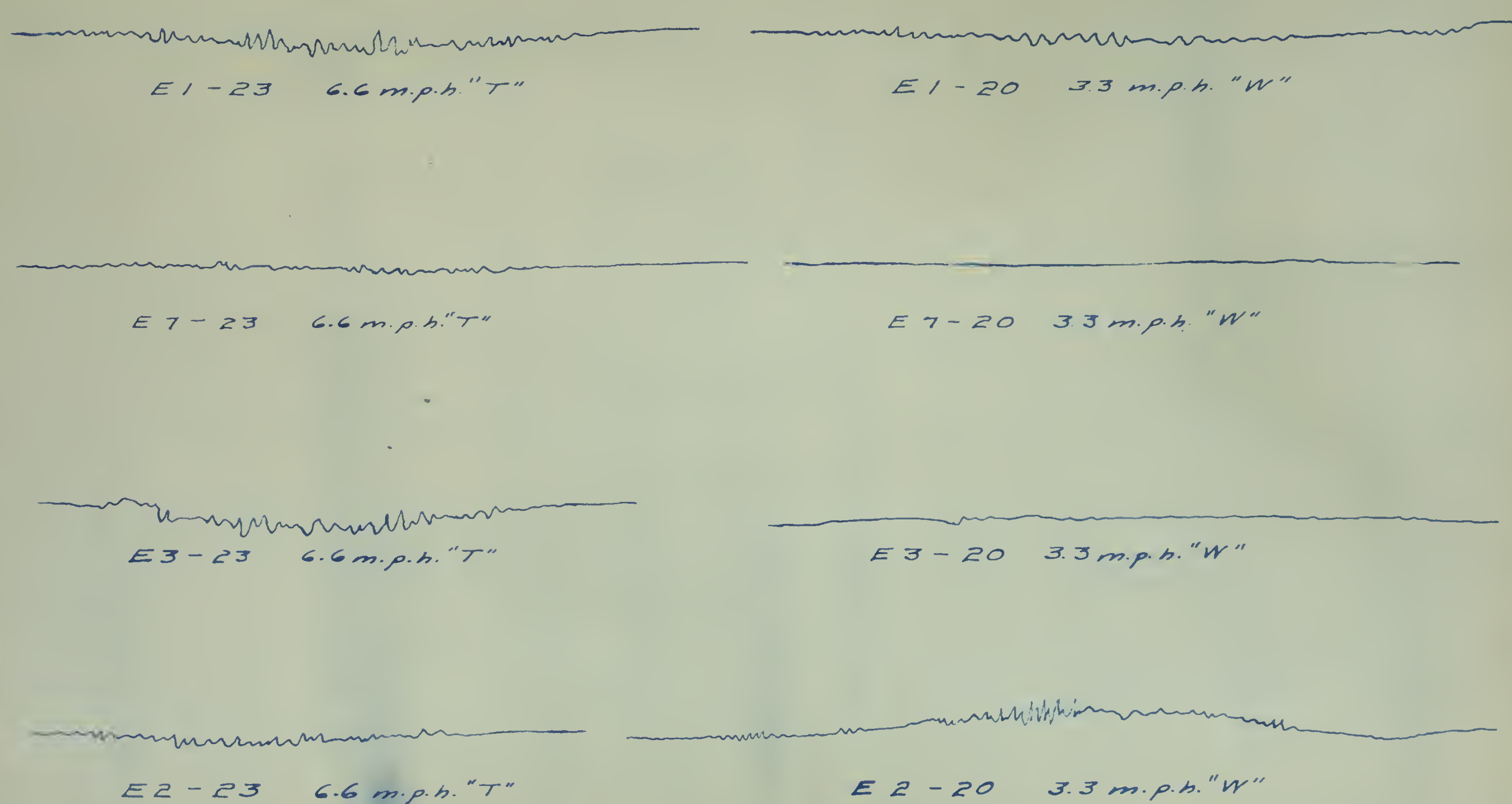
Bridge #1 Span 55' Upper Chord U_1U_2 Load:- Horse & Rig

E_1 on top inside flange. E_7 on bottom inside flange. E_3 on top outside flange. E_2 on bottom outside flange



Bridge #1 Span 55' Upper Chord $U_1 U_2$ Load: Team and Lumber Wagon

E_1 on top inside flange. E_7 on bottom inside flange. E_3 on Top outside flange. E_2 on bottom outside flange

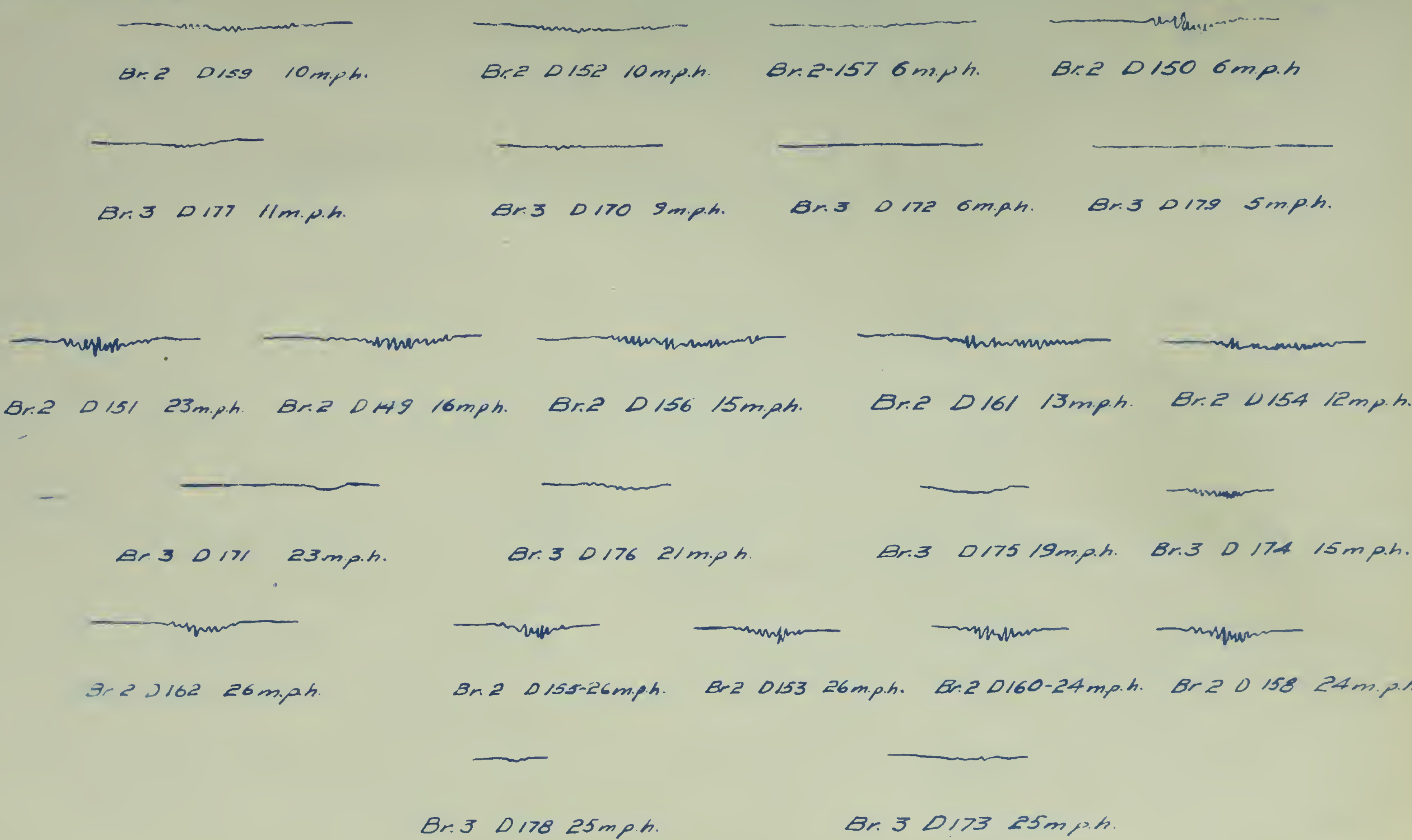


C. COMPARISON OF FLOOR WEIGHT.

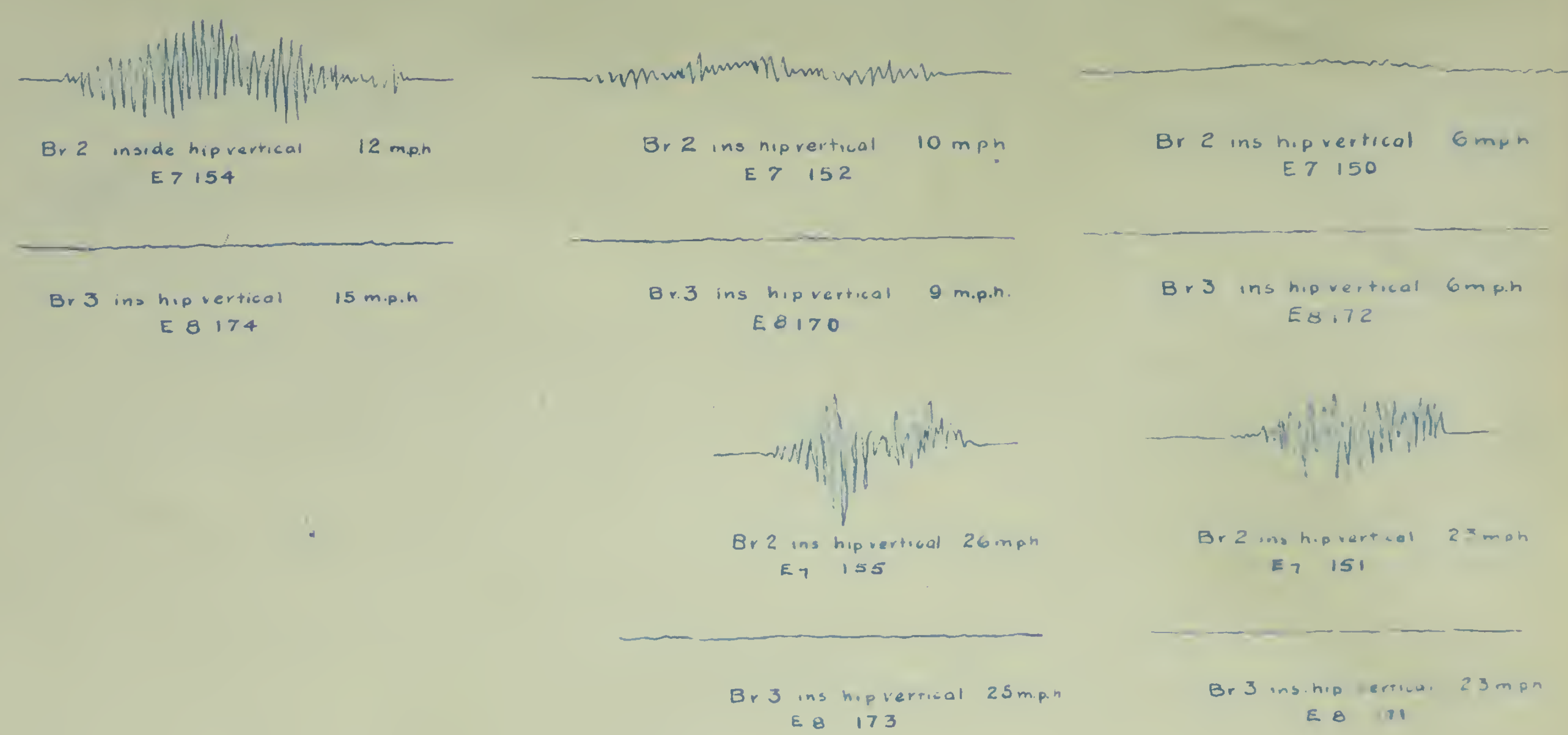
Deflectometer Diagrams. Comparison of Br. 2 (plank floor) & Br. 3 (concrete floor)
Equal spans, speeds, & loads

Load - Automobile

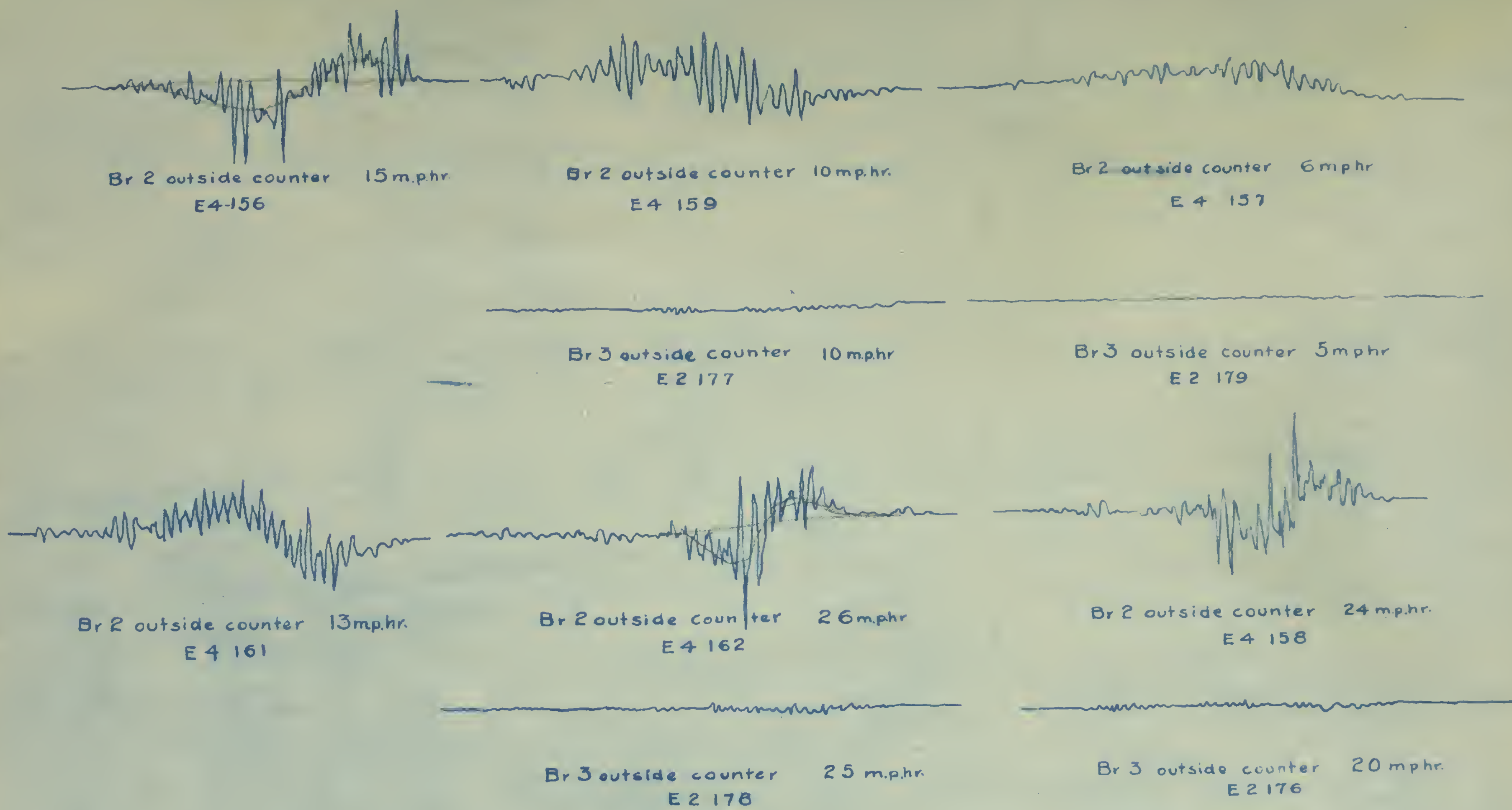
Spans - 78 ft.



Diagrams showing effect of automobile on hip vertical inside member Br 2 and 3   Br 2 plank floor   Br 3 concrete floor



Diagrams showing effect of automobile on Br 2 and 3 Br 2 plank floor Br 3 concrete floor



Diagrams Showing effect of like speeds of Automobile on like members of Br 3 (concrete floor) & Br 2 (plank floor)